Sergey M. Govorushko

Natural Processes and Human Impacts

Interactions between Humanity and the Environment

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Foreword

In this well-organised book, which is the product of many years of research, Professor Sergey Govorushko (Chief Research Scholar in the Pacific Geographical Institute of the Far Eastern Division of the Russian Academy of Sciences) provides us with a comprehensive and balanced overview of the varied environmental impacts affecting humanity. *Natural Processes and Environmental Impacts: Interactions between Humanity and the Environment* is divided logically into two parts. Part I examines natural processes and their impacts on humanity, and Part II concentrates on the reverse relationship; namely, human impacts on the environment. The processes involved are clearly explained.

The ability of humans to control natural processes varies considerably. Some are amenable to human management and some are not. Usually, humans have to adjust to such processes. On the other hand, there is normally scope to regulate human impacts on the natural environment, but it is not always easy to alter human behaviour, especially when a social (group) response is needed. This is underlined by difficulties encountered in trying to get global agreement and action to reduce greenhouse gas emissions.

Lack of knowledge is a serious obstacle in improving humanity's interaction with the natural environment. This book, by adding to our knowledge in a holistic and accessible manner, enables more effective assessments to be made of the environmental impacts of natural processes and the consequences of human activity for the state of the environment. Environmental impact assessment requires an interdisciplinary approach of the type presented in this book. Apart from being a useful book for reference purposes, it provides interesting background reading on environmental issues and brings to light some unused environmental facts that will help satisfy those who are curious. An example of an unusual fact is that involving the release of oestrogen from birth control tablets. In some cases, oestrogen enters wastewater systems, finds its way into larger water bodies and causes sex reversal in some species of fish.

It is uncommon to have a single-authored book of this encyclopaedic type. Normally, there are different authors for various components of such a book. Consequently, such books are often not integrated and the individual contributions are frequently too specialized for most readers. This book avoids these problems and the text is well complemented by numerous illustrative photographs from many parts of the world, as well as lots of maps. These improve the comprehension of its coverage.

While the examples in this book are drawn from many parts of the world, a considerable number are from Russia and nearby countries. In the absence of the publication of this book, many examples would be unknown to those who are not familiar with Russian. Therefore, the book gives English readers an opportunity to increase their knowledge about environmental issues in Russia.

Naturally, there is a cultural influence on the presentation of material in this book. Both culture and values influence the coverage of scientific publishing. For example, the selection of subjects for consideration is influenced by such factors. This is not a negative feature. It is important to consider environmental science from a number of different perspectives, and this book provides a fresh perspective.

It would be undoubtedly a mammoth task to prepare a book of this magnitude with such wide-ranging coverage in one's own language, but to do this in a foreign language is an even more daunting task. Those of us who can only access Dr. Govorushko's work in English are grateful to him for completing this daunting task and providing us with new environmental insights.

Clement A. Tisdell
Professor Emeritus
The University of Queensland and Fellow
of Social Sciences in Australia

Preface

The book we would like to present to you is an *illustrated reference book*. The aim of the book is to provide the reader with minimum necessary information covering a wide range of problematic interactions between nature and society. On *one hand*, this book tells us how different *natural processes* influence humanity, different kinds of economic activity, and engineering structures. On the *other hand*, it considers how different kinds of *human activity* affect different natural components and the environment as a whole. It reflects scientific knowledge on these problems as it stood during the late twentieth to early twenty-first century.

In creating a book like this one, *two approaches* are possible. The *first* method is to gather a large group of authors, each one being a specialist in a certain area of expertise. This method is used quite often. In spite of the evident reasonableness of this approach, it has important defects. Materials prepared by narrowly focused specialists are of little use for the purposes of comparison. Their authors are very often inclined to grossly exaggerate the role of the process considered in complication of human activities, or the 'contribution' of the activity described by them to environmental degradation. Summing up the *contributions* estimated by these specialists often adds up to 200–250% at minimum, instead of the 100% that one would expect.

The *second* method is the complex consideration of all significant processes and kinds of activity by one person. Alongside with minuses (first of all, unequal levels of the author's qualifications in different aspects of problems), there is also an evident advantage: this approach lessens subjectivism and allows more reliable evaluation of their relative significance. As for possible inaccuracies or actual errors, they can be minimized by having separate sections reviewed or edited by the appropriate specialists.

In preparing this handbook, the *second approach* was used. Review of different sections by dedicated experts was utilized, especially in preparing sections devoted to the impacts of biological processes on human activities.

The *vital differences* between this book and other similar monographs are as follows: (1) consideration of all processes and kinds of human activity from the same point of view (from positions of interactions between nature and society); (2) uniformity of all sections in the context of sequence of exposition and nature of cited data; and (3) a broad spectrum of themes, including almost all significant natural processes and kinds of human activity.

This book was partially created on the basis of the extended *Russian-language version*. The initial idea was to prepare three volumes of 700 pages of text each. The *first volume*, devoted to the influences on human activities of geologic, geomorphologic, meteorological, and hydrological processes, was published in 2007. The *second volume*, which considers biological, biogeochemical, and cosmic processes, has already been written but has not yet been published. The *third volume*, which characterizes the effects of different kinds of human activity on the environment, is currently in process.

In this connection, the creation of the English-language version of the book involved a *radical reduction* of the volume of the first part, devoted to the influences of natural processes on human activities, and *preparation ab initio* of the sections of the second part, concerning the environmental consequences of economic activities. A wide range of questions considered predetermines a sizeable volume of the book. Initially, it was assumed that the *average size* of paragraphs in each chapter should not exceed 1,000 *words*. In this connection, different sections in the first part were shortened by 2–7 times (3–4 times on average).

The *reduction in volume* was accomplished, first of all, by the complete exclusion of materials devoted to forecasting, scientific principles of measures for mitigating consequences, and methods of protection against processes. The consideration of conditions necessary for the origin of processes and characterization of their mechanisms of action were reduced to a minimum. In considering the effects of human activities on the environment, the scientific principles of measures and particular methods of mitigating environmental consequences were excluded from consideration, and the technologies used were considered minimally.

The different aspects of interactions between humans and the environment are illustrated by numerous photos. As to the *sources*, they can be divided into three *categories*: (1) some citizens of different countries – chiefly, scientific associates who sent me the needed illustrations in the form of slides, photos, or separate electronic files; (2) some organizations; and (3) sites of different international, national, and local organizations. I am grateful to the authors and organizations granting permissions for the use of the photos in this book. It seems to me sometimes that collecting permissions was more difficult than writing the text of the book. Lists of copyright holders for maps and photographs are given in an attachment.

The author wishes to express his gratitude to Academician P.Ya. Baklanov, Director of the Pacific Geographical Institute, FEB of RAS (Far Eastern Branch of the Russian Academy of Sciences), for every possible support over many years in conducting the above investigations.

The support and assistance of current and former colleagues at the Pacific Geographical Institute are also gratefully acknowledged; included are V.B. Primak, Dr. S.M. Krasnopeev, Prof. B.V. Preobrazhensky, V.N. Nesterov, Prof. A.M. Panichev, V.V. Aramilev, Prof. A.V. Moshkov, A.V. Vlasov, E.P. Kudryavtseva, V.A. Solkin, Prof. S.S. Ganzey, Dr. V.V. Ermoshin, T.A. Krasnopeeva, and Prof. A.P. Kulakov.

Numerous colleagues from Russia have also contributed indirectly to this book, including Prof. P.F. Brovko (Far-Eastern State University), Prof. Z.M. Azbukina, Prof. V.N. Kuznetsov, Dr. I.A. Kruglik, Prof. V.A. Kostenko (Institute of Biology and Pedology, Vladivostok), Dr. Yu.M. Yakovlev, Prof. A.Yu. Zvyagintsev, Dr. K.A. Lutaenko (all from the Institute of Marine Biology, Vladivostok), Dr. P.G. Ostrogradsky (Mountain-Taiga Station, Gornotaezhnoye village, Primorsky Krai), Dr. V.N. Glubokov (Far-Eastern Regional Research Hydrometeorological Institute, Vladivostok), Prof. G.L. Leonova (Research Institute for Epidemiology and Microbiology, Vladivostok), T.S. Aramileva (Primorsky Krai hunting and fishing society, Vladivostok), V.A. Kantor (Greenpeace/Russia, Moscow), Prof. S.P. Gorshkov, Prof. A.A. Svitoch, Dr. A.I. Tyurin (Moscow State University, Moscow), L.V. Desinov, S.A. Bulanov (Institute of Geography, Moscow), Prof. V.D. Ilyichev (Institute for Environmental and

Evolutional Issues, Moscow), Yu.A. Murzin (Institute of Permafrost Studies, Yakutsk, Russia), and others.

The author has had the unique opportunity of becoming acquainted and collaborating with numerous international colleagues. Of particular note are Dr. I. Kelman (Centre for International Climate and Environment Research, Oslo, Norway), Dr. L. Bosher (Loughborough University, England), Prof. C. Tisdell, Dr. K. Gillow, Dr. M.J. Hansen (all from University of Queensland, Brisbane, Australia), Prof. H.J. Walker (Louisiana State University, USA), Dr. J.D. Bultman (Naval Research Laboratory, Department of the Navy, Washington, DC), Dr. S.F. Trush (National Institute of Water & Atmospheric Research, Hamilton, New Zealand), Dr. S. Beltaos (National Water Research Institute, Environment Canada), Dr. L. Stoffel (Swiss Federal Institute for Snow and Avalanche Research, Davos, Switzerland), G. Cook (Earth Island Institute, San Francisco, USA), Dr. V. Haddad Jr. (São Paulo State University, Botucatu, Brazil), Dr. M.C. Larsen (US Geological Survey, Reston, USA), Prof. J. White (Women's and Children's Hospital, Adelaide, Australia), Dr. R. Pyle (Bartol Research Institute, University of Delaware, USA), Prof. J-P. Chippaux (Institut de Recherche pour le Développement, Cotonou, Bénin), and Dr. P. Duffy (P.J.B. Duffy and Associates Ltd., Vancouver, Canada).

Of major importance to the author is the positive attitude and helpfulness of Ms. E.Ya. Litachevskaya for translation of enormous number of papers and other materials from English to Russian, Ms. L.P. Slavinskaya, Ms. A.A. Polikarpova for assistance in preparation of the manuscript for publication, and Ms. E.V. Oleinikova for preparation of electronic versions of maps.

Special thanks to Ms. D.M. Miller (Boulder, Colorado, USA) for close editing of the manuscript and her persistence in overcoming differences between the Russian and English, which, as I hope, allowed the book to become clearer for the Western reader and scientific editor of Chap. 5, Dr. M. Sullivan (Environmental Services Ireland, Sligo, Ireland). The author would like to thank the following translators: V.M. Karpets (Chaps. 1–4, 6–10, Preface, Introduction), Yu.A. Kalashnikova (Chaps. 11 and 13), Dr. V.Z. Kalashnikov (Chap. 5), and R.N. Bycov (Chap. 12).

The author is aware that this book, like any other work, is not free from defects. These defects may be attributed to the following circumstances:

1. *Differences in scientific approaches in Russian and Western literature.* The book was, for the most part, written with the use of materials provided by Russian scientists. There are certain differences between the scientific schools, which are particularly evident in terminology. For example, the toxicity of animals, depending on its character, can be specified by the terms *poisonous* and *venomous*. In Russian, the toxicity of animals is determined by a single word. The term *ice jams,* on the contrary, has two different meanings in Russian, but in Western literature there is only one term to describe *ice jams*, which does not discriminate between spring ice jams and autumn ice jams. Also, the terms *zoonoses*, *zooanthroponoses*, and *anthroponoses* have other meanings in Russian, and so on.
2. *Weak development of some branches of science in Russia.* The degree of development of one or another branch of science is frequently determined by the geographical conditions in the country under consideration. For example, Australia is characterized by a high level of investigation of noxious marine animals, while in Russia great attention is paid to the study of processes related to permafrost. It is natural that such differences are caused by the significance of a process to a country, which can also be seen in the amount of financing.

3. *Defects connected with using translated foreign publications.* I have not infrequently used translated books as sources of information. The interval between publication and the translation sometimes was more than 10 years. Besides mistakes being made in the translation process, I sometimes used different meanings of some terms.
4. *Defects connected with translating and editing.* There often were problems in reverse translation. Some of my sources were translated into Russian (from English, German, French, etc.). In preparing this book, the reverse translation from Russian to English was necessary. Such a translation rather often differs from the initial work, and I needed to search for the original intended meanings. This problem arose with geographic names and family names.
5. *My mistakes.* Evidently, I did not succeed in avoiding mistakes. As the saying goes, 'He that never climbed, never fell'.

Therefore, the author will be very grateful to all who, after discovering errors, uncertainties, etc., in the book, send information concerning them to me at sgovor@tig.dvo.ru. In addition, e-mailed photos illustrating different aspects of interactions between humanity and the environment also would be helpful.

Introduction

The *interaction of society and the environment* is a mutual process. *On the one hand*, natural processes influence people, resulting not infrequently in loss of life and property and obstruction of human activities. *On the other hand*, different kinds of human activity cause changes in the environment. At early stages of human development, influences on humanity were predominately exerted by natural disasters. *The first known natural disaster* overtaking people took place about 1 million years ago in a dry riverbed in Ethiopia. A sudden flood caught a group of our forefathers off their guard. Their bones were found under layers of fluvial deposits (Kukal 1985).

The *influences of people on nature* consist of the withdrawal of natural resources and the introduction of products of life (wastes) into nature. Human population levels were once insignificant, and the needs of people coincided with those of animals similar in physiology, resulting in their conflict-free coexistence with nature. The areas of human distribution were limited by zones of warm climate and food abundance. The gathering of food was the primary activity, and, later on, human activities changed to a combination of gathering, hunting, and fishing. Little by little, the population upsurge resulted in a need to expand the area of activity; up to 500 ha was required for the survival of one person in a *gathering society*, and up to 1,000 ha was required for societies that engaged in *hunting* (Vaschekin et al. 2000).

From the environmental viewpoint, food *gathering* was a safer activity as compared with hunting; this fact became especially evident after humanity learned at the end of the Palaeolithic Age to make use of *fire*. By this time, 'fire technology' consisted of burning out forests and other vegetation in the course of hunting. At that time (more than a hundred thousand years ago), the systematic use of fires as a *universal tool of hunting* resulted in sizeable environmental consequences, including environmental degeneration and reductions in the quality and quantity of bioresources. It is believed that environmental destruction contributed to the *extinction* of some fauna species.

There were the succession of plants (forests were replaced by savannas, steppe, and bushes) and climate transformation. Over large areas, 'pyrogenic landscapes' came into existence that were subjected to erosion, desertification, and decreases in groundwater levels. The use of fire allowed the expansion of areas settled by humans, which, in turn, resulted in new forms of interaction with nature (for example, construction of dwellings in places where caves were absent). In the Palaeolithic Age, the *first stage of globalization* – development of the land by humans – was essentially completed (Human occupies Mother Earth 1997).

In the course of hunting–gathering activities, only those resources were used that were provided by nature itself, and humans influenced it extensively. Eventually as humans spread over the Earth, hunting and gathering could no longer support the growth in populations and became a brake on social progress. As a consequence, a transition to a new method of interaction with nature – *material production* – took place 10,000–12,000 years ago.

Strictly speaking, the foundations of this method already existed in the Palaeolithic Age because people made instruments of labour. For example, hunting methods became more complicated, and tools were improved (e.g., spears, bows with arrows, darts, missile sticks, traps, nets, and lassos). However, the tools that were developed were used primarily for hunting–gathering activities. The Neolithic revolution consisted mainly of the changeover to farming and cattle breeding, and it resulted in the *abrupt intensification of anthropogenic impacts* on the environment (Vashchekin et al. 2000).

In the Neolithic Age (8000–3000 BC), the area of 'pyrogenic landscapes' abruptly increased; however, the forests were destroyed by fires for purposes of *agriculture and acts of war* (initially, in the course of conflicts between tribes, and later on between states, rather than for purposes of hunting). The slash-and-burn system resulted in one of the most essential environmental consequences: the desertification of two billion hectares of fertile lands, which is greater than the area of presently cultivated lands.

The major *agrarian centres of ancient times* were the Middle East, Egypt, India, and east China. By the early Common Era – that is, 2,000 years ago – the development of agriculture resulted in a number of local environmental crises due to soil erosion and salinization. These crises caused the weakening and collapse of a number of states in the Middle East (Danilov-Danilyan et al. 2001). It is also believed that slash-and-burn activities were one of the reasons for the collapse of the Mayan civilization.

The deforestation of vast territories, from the Mediterranean to China, was carried out for purposes of expanding agricultural holdings, constructing houses and ships, and obtaining fuel wood. Deforestation resulted in changes in water cycle intensity over part of Europe and contributed to the initiation of desertification within the belt from north Africa to inner Mongolia. So, a regional environmental crisis developed (Danilov-Danilyan et al. 2001). Cattle breeding made a considerable contribution to desertification, especially in the regions of the Mediterranean and Middle East. In a monograph by Zh. Dorst (1968), the author says that the nomad is not so much a son of the desert as its father.

The *development of agricultural technologies* gave rise to accelerated growth in population sizes, generally in the eastern Mediterranean and valleys of the Hwang Ho and Indus Rivers. In these cradles of civilization, the population sizes had reached from 40 to 50 million people 4,000 years ago (Kapitsa 1995). By the early Age of *Discoveries* (1650), made possible due to the development of the shipbuilding and navigation technologies, the Earth's population had reached 450 million people. The Discoveries resulted in the planetary spread of agricultural technologies.

Another important consequence lies in the fact that previously unknown plants from the New World were delivered and began to be cultivated in the Old World. This resulted in a new impetus to population growth. If, within the first 1,650 years of the Common Era, the growth rate was 0.04% a year, it increased more than seven times, and for a very short period it reached 0.3% (Kapitsa 1995).

A flow of emigrants from Europe, where famines were at that time characteristic, to new territories was one more consequence of the Discoveries, which caused a displacement of natives from America, Australia, and, partially, Africa. In Asia, a similar process occurred as Russia's earliest explorers (pioneers) developed the great spaces of Siberia and the Far East and brought farming standards to these regions. The great migration of peoples differed from the previous ones in that the peoples possessing more modern technologies of production of material values as compared with the natives encroached upon new regions.

The globalization of the farming industry, the *second stage of general globalization*, lasted about 10,000 years. Just this stage initiated the global destruction of natural ecosystems in the land. Agricultural development was accompanied by the replacement of complicated natural ecosystems by simplified agrocoenoses, reductions in biodiversity, introduction of new species, and disturbances of the biogeochemical cycle – the greatest changes in natural ecosystems (Danilov-Danilyan and Losev 2000).

A turning point in the character of population dynamics fell at the beginning of the Industrial Revolution, when *industrial technologies* emerged. If high birth rates and high mortality were characteristic of the previous period, then discovery and introduction of sanitary-hygienic technologies resulted in decreases in mortality and increases in lifetime against the background of maintenance of high birth rates. The Industrial Revolution provided people with energy from fossil fuels, which sharply accelerated the process of destruction of natural ecosystems and resulted in collisions of civilization with nature (Losev et al. 1997).

The distribution of industrial technologies throughout the world has lasted 200 years and has become the *third stage of globalization*. The industrialization and scientific and technological advances intensified the destruction of the environment. On the one hand, the development of industry and its infrastructure required the additional decay of natural ecosystems, while on the other hand, towards the end of the third stage of globalization, new kinds of impact on the environment and directly on humans appeared*: pollution of natural components* by production waste and the influences of *anthropogenic physical pollution* on living organisms (Danilov-Danilyan and Losev 2000).

In turn, the *number of natural processes* that caused real difficulties for human activities *increased*. An intensification of industrial and civil engineering resulted at times in the necessity to erect objects on *expansive and collapsing soils*, under conditions of *karst*, and so on. Railroads were not infrequently constructed on *bogs*. An example of such a railroad is the Liverpool–Manchester railroad (Great Britain), which crossed the large Chat Moss swamp. Its construction was finished in 1830 (Anderson and Trigg 1981). Building and operating harbour installations were not infrequently complicated by *abrasion* and other natural processes. The growth of population density has often resulted in increased danger of *epidemics*.

The destruction of the natural environment occurred most intensively at that time in the industrially advanced countries. Manchester, in Great Britain, became the first industrial city in the world. The first legislative acts aimed at reducing waste are associated with this city. These were the Acts of 1863 and 1872, aimed at decreasing discharges of hydrogen chloride into the atmosphere in the course of caustic soda production. These emissions adversely affected public health and the state of the environment (Danilov-Danilyan et al. 2001).

A combination of industrial and agricultural effects caused global disruptions – especially disturbances of the biogen cycle closedness, quick reductions in biodiversity, and changes in the chemical composition of natural components. These effects appeared in the early twentieth century in place of previously existing areas of local disturbances in environmental stability. In the twentieth century, this process accelerated to the extent that it became evident over the period of only one generation, and processes that actually had begun much earlier were 'discovered' only in the second part of the twentieth century.

An idea of changes in the extent of environmental effects can be provided by *figures on increases in available power and material flows*. A *human-gatherer* used his muscular energy to collect food, with the power of his metabolism being 140 W. The power of a *human-hunter*, in connection with a widespread use of fire, increased this amount to 240 W. In case of hunting–gathering activity, the total mass of all materials consumed every year did not exceed 1 ton per person.

In *agricultural societies*, the available power varied from 500 W in the case of traditional farming to 2,000 W for more recent agricultural practices. A human-agrarian was in need of about 4 ton of biomass (food, 0.5 ton; fodder, 2.7 ton; and wood, 0.8 ton).

The power used per person in *modern industrial society* is, on average, 3,200 W, while this value reaches more than 7,000 W in the developed countries. At present, 50 ton of substance per man are produced, and 20 ton of them go to waste as rock refuse. The remaining mass consists of building materials (30–40%) and agricultural raw materials, timber, minerals, fuels, and other materials (60–70%) (Environmental problems 1997; Sustainability indicators 1997).

Properly, the *scales of impact of natural processes on human activities* to which the first part of the book is devoted have sharply increased. It should be noted that attributing some natural processes to one or another group is far from indisputable. We have grown accustomed to classifying scientific knowledge in accordance with the departmental organization of educational institutions; however, it is unlikely that such a principle of separation of natural processes is justified in this case. For example, waterlogging is in essence a *hydrological* process. At the same time, the erection of structures on peats and peaty grounds is an *engineering-geological* problem.

The assignment of a number of other processes to one or another category is also quite debatable. For example, subsidence, karst, thermokarst, solifluction, thermoerosion, and thermoabrasion are at the intersection of *geological* and *geomorphologic* processes. Aufeises, mudflows, avalanches, glaciers, and abrasion can be categorized as both geomorphologic and hydrological processes.

A tsunami may be equally considered to be a *geological* (from the viewpoint of origin) and *hydrological* (from the viewpoint of mechanism of action) phenomenon. By analogy, wind erosion is a *meteorological* process in terms of its determining cause and a *geomorphologic* process with respect to its relief-forming role.

Returning to the departmental organization of educational institutions, it should be noted that, as a rule, the extension principle predominates here; that is, all the processes related, in one way or another, to this discipline are attributed to the scope of this science. By analogy, if we look through the programme of any significant conference, we will find that there are many processes attributed formally to other groups. For example, workshops devoted to earthquakes, volcanic eruptions, floods, glaciers, karst, and other natural phenomena are always an integral part of international geomorphologic conferences. However, substantiation of the division of natural processes is, by no means, a purpose of this book.

One more 'delicate' subject consists of the fact that the topics under consideration can not always be attributed to the processes *per se*. For example, *floating earths, quicksands*, *fog*, and so on should be called phenomena rather than processes. *Temperature*, *solar radiation*, *humidity*, *etc*., are most probably some environmental characteristics. However, when using formulations like ‘variation of temperature’ or ‘humidity dynamics’, these will just be considered to be processes. In this book, all of this is integrated into the term *process*.

As a rule in this book, a separate paragraph is devoted to each natural process and kind of human activity. Text is accompanied by photos with detailed captions. In the author’s opinion, they will improve the understanding of the text for non-specialists (as the saying goes, a diagram is worth many words). For the sake of convenience, a conversion table covering units of the metric system and units of the Anglo-American system is included in the book, in addition to the Index.

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Contents

Part I

Natural Processes and Their Impacts on Human Activity

1 Geological Processes

Abstract

Geological processes largely originate in the Earth's interior. They are caused by gravitative differentiation, forces that arise in the course of Earth's rotation, radioactive decay, and so on. These diverse processes differ in rate, thickness of the affected mass, and scale. The energy sources for different geological processes are internal forces that operate in the Earth's crust and mantle (earthquakes, volcanic eruptions, and tsunamis) and physical, chemical, and phase transformations that take place in the interior of the Earth (cryogenic processes, karst phenomena, swelling and shrinkage, subsidence, and so on). Geological processes are of primary importance in the creation of surface relief. The significance of different geological processes for human activities is characterized by strong differences. Seismic processes (earthquakes, volcanic eruptions, and tsunamis) are of primary importance.

Keywords

Geological processes • Rate of process • Geological conditions • Geological mechanisms • Human activity • Economic loss • Mortality

1.1 Seismic Processes

Seismic (from the Greek *seismos*) processes are related to oscillations in the lithosphere. The *lithosphere* is the Earth's outer shell, measuring 50–200 km in thickness. It includes the Earth's crust and a portion of the uppermost mantle. The lithosphere is not entirely solid; it is divided into separate plates. Seven great lithospheric plates (African, Antarctic, Eurasian, Indo-Australian, North American, Pacific, and South American) and seven smaller plates (Arabian, Caribbean, Cocos, Juan de Fuca, Anzac, Philippine, and Scotia) are generally identified. As a rule, the positions of the plates relative to each other are unstable.

The following *types* of relative movements of the plates have been identified (Neshyba 1991): (1) divergence (plates move in opposite directions); (2) convergence (one plate is subducted under the other); and (3) transform sliding (one plate slides relative to the other). The rates of their motion reach 1–10 cm/year. The total length of the sections along which plates collide corresponds to the length of the boundaries where plates are separating. In both cases, this value is about 60,000 km (Koronovsky and Yasamanov 2003).

The motion of tectonic plates is quite *slow,* but due to its long duration, the absolute values of displacement are considerable. For example, a displacement of the North American Plate relative to the Pacific Plate

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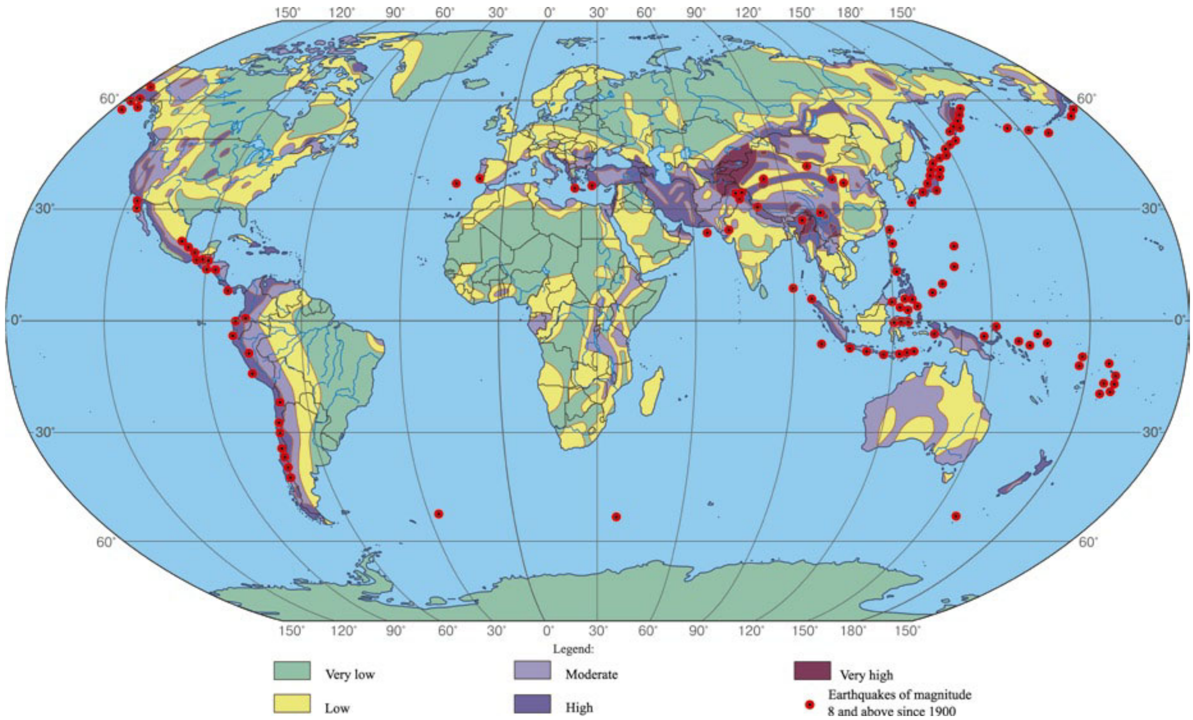

Fig. 1.1 Global seismic hazards (Adapted from http://geology.about.com/library/bl/maps/blworldindex.htm; Gere and Shah 1988)

reached 400 km from the end of the Mesozoic (Aprodov 2000). In addition to horizontal motions, slow *vertical motions* at a speed of 2–12 mm/year are also characteristic of the crust.

Vertical tectonic movements have certain effects on *human activities*. Many places are known where whole towns are now at the bottom of the sea, while the port installations, on the contrary, are on land. Examples of *submerged settlements* are, particularly, ancient Greek colonies on the Black Sea coast: Sozopol, Bulgaria; and Dioskuria, around the modern Sukhumi. In turn, the berths in Novaya Zemlya constructed by the coast dwellers in the eighteenth century are now *above sea level* and at a good distance off the coast (Koronovsky and Yasamanov 2003).

However, the scale of damage related to slow tectonic movements is absolutely incomparable with the extent of the negative impacts of other seismic processes on human activities. Overwhelmingly, they are confined to the edges of lithospheric plates where, due to tectonic movements, zones of great stress are formed. The most significant seismic processes are considered below.

1.1.1 Earthquakes

Regions where destructive earthquakes are possible occupy about 10% of the land area of Earth (Fig. 1.1); however, half of the human population resides there. One third of the population in China and one-half of the Japanese population live in seismic danger zones.

The reason for all major earthquakes and 99% of weak earth shocks is tectonic processes. In addition, there are volcanic (generally, owing to explosions of magmatic gases) and collapse (related to failure of the roofs of caves and abandoned mines) earthquakes. We will be dealing mainly with *tectonic earthquakes*, which are a consequence of rock ruptures in the Earth's interior.

A place deep in the Earth where a crack begins to form is called an *earthquake focus*. The focus centre is called the *hypocentre* of the earthquake, while its vertical projection onto the Earth's surface is referred to as the *epicentre*. Sometimes, the ruptures resulting in very strong earthquakes reach the Earth's surface. The *lengths of cracks formed* can be considerable. The record for this characteristic was established by the San Andreas earthquake on 9 January 1857 in the United

Photo 1.1 An example of an earthquake accompanied with horizontal offset of lithospheric blocks is the magnitude 6.9 El Centro, California, earthquake of 15 October 1979. Economic loss from this earthquake was due to damage of canals, irrigation ditches, and subsurface drain tiles disturbed by the movement along the Imperial Fault. The image shows the offset of lettuce rows across the fault (Photo credit: U.S. National Geophysical Data Center, photo by University of Colorado)

States, when the rupture length proved to be 400 km (Aprodov 2000).

With respect to the hypocentre (*focus*) depth, earthquakes are subdivided into three groups (Koronovsky and Yasamanov 2003): (1) shallow-focus (0–60 km); (2) middle-focus (60–150 km); and (3) deep-focus (150–700 km). In the majority of cases, earthquake hypocentres are concentrated in the upper part of the Earth's crust at depths of 10–30 km, which is distinguished by maximum rigidity and fragility.

In order to quantitatively estimate earthquake *intensity*, the magnitude of an earthquake (based on the so-called Richter scale) is computed on the basis of vibration measurements in seismic monitoring stations. Because the magnitude scale is logarithmic, a magnitude increase of unity implies a tenfold growth in ground displacement amplitude at the surface. In other words, an earthquake with a magnitude of 8.0 is ten times stronger than an earthquake with a magnitude of 7.0, and so on. The significant peculiarity of the Richter scale lies in that the magnitude characterizes the energy at the earthquake's origin, not on the Earth's surface. A shallow-focus earthquake with a low magnitude can have much more serious consequences than a strong deep-focus one. In media reports concerning the occurrence of earthquakes, the strength of the Earth's tremor is generally identified with the Richter *magnitude*, which is *misleading* (Govorushko 2007a).

It is quite important to be aware of the earthquake strength at the *focus,* but the *intensity of its effect on the surface* is much more important. The question at issue is that it (intensity) is not a directly measured quantity, and its determination is entirely subjective. Therefore, it is necessary to survey the devastated regions, inspect damaged structures, and interview witnesses for the purpose of determining their responses to the seismic loads and other factors. There are several earthquake *intensity scales*: the Mercalli scale, the scale of the Japan Meteorological Agency, the MSK scale, and the Chinese scale.

On the whole, the *deeper* the earthquake focus, the *greater* the area of its effect but the *lower* its intensity. There are several other factors that influence both the tremor zone area and the intensity of the shocks' manifestation on the surface.

All of these factors are related to differences in *geological engineering conditions*. The most important of them are the following (Aprodov 2000): (1) soil bearing capacity (hard country rocks are most favourable, while thin-layered, loose, slimy, or peaty soils are most dangerous); (2) water saturation (the greater the

Photo 1.2 The destructive character of the magnitude 7.5 Neftegorsk earthquake in Sakhalin on 28 May 1995 was caused mainly by the earth tremor. As a result, 17 of 22 panel five-storey buildings were completely ruined; two other buildings were burned. As a result of the quake, 2,247 of 3,176 residents of the town were caught in the rubble; 1,992 of them died (Photo credit: G.L. Koff, Institute of Lithosphere, Moscow, Russia, 30 May 1995)

saturation, the greater the danger); (3) presence of ledges of country rocks under the cover of loose ground (it results in the growth of the vibration amplitude of the loose ground particles); and (4) surface relief (vibrations intensify at sharp slope discontinuities and crests, while deep valleys damp vibrations). These factors can increase vibrations by 1–2 points.

Every year, seismic stations record about 500,000 earthquakes; however, overwhelmingly, these are weak, non-destructive shocks. The number of earthquakes capable of demolishing structures is about 5,000.

The *devastating effects of earthquakes* are mainly determined by four groups of factors: (1) shaking as well as subsequent changes in ground properties; (2) changes in the elevation marks of surface patches; (3) initiation of dangerous natural processes; and (4) demolition of structures due to the secondary effects of earthquakes (fires, explosions, etc.). In the *first group*, one can include shaking, ground rupture, ground subsidence, and soil liquefaction.

The negative effects of *shaking* are strongly related to the duration of the vibrations. Every additional shock results in new destruction in the walls, floor girders, foundations, and other parts of the structures. As cracking and breaking are aggravated, the strength of structures is reduced more and more, and they, little by little, fall to pieces. *Earthquake shocks* are the most evident display of earthquakes, but they are responsible for only a part of the demolition and losses. *Ground discontinuities* (cracks, displacements) also occur, which result in deformation and demolition of structures. Their destructive role is especially significant when the top edge of a rupture crosses built-over land. In this case, there is local damage to building foundations, breakdowns of road beds, and ruptures of underground facilities, such as water supply and gas pipes (Seismic dangers 2000).

Other effects of earthquakes are less known. *Subsidence of the Earth's surface* is a serious and fairly common effect of earthquakes. Due to vibrations that occur during the earthquake, soil consolidation takes place, which results in soil volume reduction and cavitation and, as a consequence, in damage to structures (buildings, pipelines, bridges, roads, etc.). In this

Photo 1.3 Ground liquefaction during earthquakes is not widespread, since it requires coincidence of a number of conditions. This photo illustrates the negative impact of ground liquefaction. In the course of the magnitude 7.4 earthquake of 16 June 1964, Niigata prefecture, Japan, several big buildings slowly subsided and leant in liquefied ground. Thanks to the durability of their construction, the buildings were hardly damaged at all. Uneven subsidence inflicted the most damage in Niigata, Japan. About one-third of the city subsided by as much as 2 m due to sand compaction. The earthquake killed 26, destroyed 3,018 houses, and damaged 9,750 buildings (Photo credit: U.S. National Geophysical Data Center)

respect, banked ground is most dangerous, especially where the ground was previously waterlogged.

The frequency and the value of surface subsidence depend on the *nature of the soils*. For example, during the earthquake of 1948 in Ashkhabad, Turkmenistan, various sectors of the city suffered different effects. In the north-eastern part of the city, where loamy sands were present, destruction was maximal. The western sector, which had a prevalence of more compact loams, suffered a little. The buildings erected on the thick series of coarse gravel were not significantly affected (Larionov 1974).

Soil liquefaction during earthquakes occurs under the following conditions: (1) sufficient duration of the earthquake (10–20 s), (2) certain frequencies of shocks, (3) certain composition of the ground (generally, sand), and (4) water saturation. Owing to vibration, soil turns from the solid state to a smeary, semiliquid state and resembles running sand. Such ground fluidization is characteristic of coastal lowlands. During the earthquake in June 1964 in the coastal area of Niigata (Japan), several large buildings seeled in the liquefied soil, and the angle of underlay of one of these buildings reached 85° (Photo 1.3). As the movement was slow and the building structure was sturdy, no harm was done (Gere and Shah 1988).

A change in elevation marks occurs as a result of subsidence or rise of separate portions of the surface. Occurrences of *subsidence* when built-over land is submerged are most dangerous. The uplift of separate sections also has a disadvantageous effect. Such adverse effects can include putting drainage networks and irrigation canals out of action due to changes in runoff direction and disabling of harbour installations due to increases in height that prevent their operation.

Photo 1.4 It was ground displacement caused by the earthquake of 1994 that destroyed this overpass in California (U.S.). Two sections of the overpass bridge were demolished due to displacement of their buttresses by as much as 10–15 cm. A policeman riding along the bridge on his motorcycle died during the very moment of collapse (Photo credit: J. Dewey and courtesy of U.S. Geological Survey)

The *third group of factors* that cause destruction of structures includes dangerous natural processes caused by earthquakes: tsunamis, landslides, mudflows, avalanches, rockfalls, screes, and seiches (Govorushko 2007c). The mechanisms of these processes and the characteristics of their impacts on engineering structures are described in the appropriate sections of this chapter.

The *fourth group of factors* includes destruction caused by the consequences of earthquakes. It includes *fires*, *floods* due to breaks in dams and water conduits, *explosions,* and other occurrences. *Epidemics* and *hunger* also contribute to mortality. It is difficult to *rank the earthquake factors* by severity of destruction and death toll, but the *top rank* probably belongs to *landslides*. For example, during the earthquake of 1556 in China, most of the 830,000 deaths were caused by landslides. The group of factors related to soil property changes occupies, evidently, *second place* (with allowance for seriously wounded people who later died). Then, most probably, tsunamis, *mudflows*, and *avalanches* follow. Immediately after, one can likely place the demolition of structures and deaths caused by earthquake *consequences*.

Photo 1.5 At times, the impact of earthquakes on motor transport implies direct damage to cars. This photo demonstrates a number of cars in Izmit, Turkey, that were crushed by subsided buildings. This magnitude 7.4 earthquake of 17 August 1999 killed approximately 18,000, demolished 113,000 buildings, and caused $10–15 billion in property damage (Photo credit: Murat Sungur Bursa (Turkey))

Earthquakes have serious effects on all kinds of human activity. The impact on the *industrial and civil sectors* and on different modes of *transport, transmission, and communication is* most evident. More rarely, agriculture is affected. The impact on *crop production* is, first of all, evident when *irrigation canals* are put out of action. Quite often, *mass mortality of livestock* is observed. The average annual mortality and economic losses due to earthquakes can be estimated at 15,000 people and US$20–30 billion (Govorushko 2009a).

Various effects of earthquakes on human activities are illustrated in Photos 1.1–1.5.

1.1.2 Volcanic Eruptions

Like earthquakes, volcanic eruptions are frequent newsmakers. All together, about 2,500 volcanoes exist on Earth; during the last 3,500 years, only about 959 volcanoes (including 811 on land and 148 under water) have erupted (Guschenko 1983). About 360 million people live in dangerous proximity to active volcanoes. On average, about 50 volcanoes erupt each year (Smith 1992). The distribution of active volcanoes is shown in Fig. 1.2.

A volcanic eruption is a complex phenomenon that may involve any of several processes: (1) ejection of debris (bombs, lapilli, sand, ash); (2) volcanic gases (carbon monoxide, carbon dioxide, and water vapours containing admixtures of hydrogen sulphide, muriatic and hydrofluoric acids, sulphurous and sulphuric oxides); (3) lava flows caused by rim and issue from crevices on a volcano's slope or those directly in earth; (4) burning volcanic clouds; and (5) volcanic mudflows (lahars). Any eruption manifests itself in several processes; still, as a rule, only one or two of them occur in any one eruption.

Depending on the size of the particles, the distance of their flight may range from several kilometres (bombs) to several thousand kilometres (ash).

Ejection of ash is extremely destructive for the economy. The effects of volcanoes are dangerous, first of all, for the following human activities: (1) transportation (first and foremost for aviation and motor vehicles); (2) agriculture; (3) electric power transmission and communication; and (4) residential buildings.

Transport problems arise, *first*, from hampered movement on ash-covered highways and runways. The *second* complicating factor lies in a drastic increase in friction in machine and motor parts including compressor and turbine vanes and in the abrasive impact of ash on protruding surfaces of planes (cockpits, front edges of the wings and tail rudder, the motor cap, the fairing of fore radar, etc.). The *third* problem is a dramatic decline in the

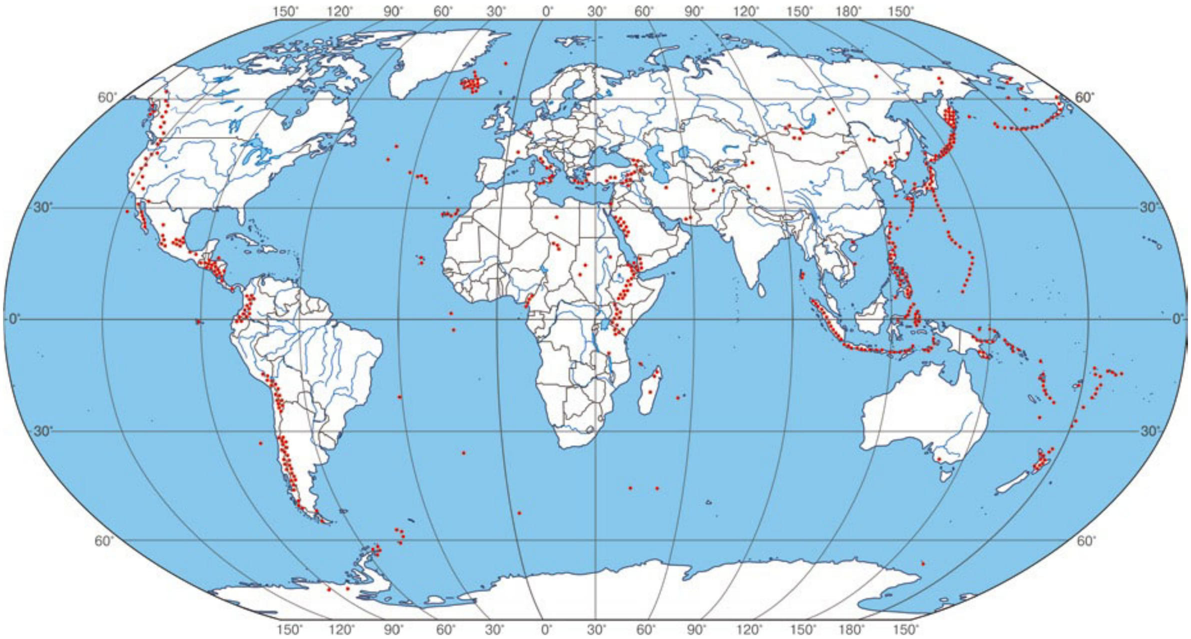

Fig. 1.2 Distribution of active valcanoes. The valcanoes erupting in the last 10,000 years are shown (Reproduced with permission of global Volcanism Program, Smithsonian Institution)

Photo 1.6 This photo illustrates structural damage of a DC-10 airplane at the U.S. Naval Air Station in the Philippines. Heavy volcanic ashfall occurred when the Pinatubo volcano erupted in June 1991. Ash deposition on the wings and tail unit resulted in mass unbalance that forced the airplane to sit on its tail. Flying through volcanic ash clouds destroyed engines in 3 of 11 aircraft (Photo credit: R.L. Rieger, U.S. Navy/NGDC Natural Hazards Slides, 17 June 1991)

efficiency of jet engines up to the point of collapse when ash is sucked in since the melting volcanic glass it contains covers injectors, reducing the efficiency of fuel mixing with air coming into the engine. *Fourth*, ash may disable energy generators and navigation aids. The *fifth* complicating factor is declining visibility, which has contributed to wrecks and catastrophes. Problem *six* is connected with the considerable specific weight of ash, which leads to great mechanical loads.

The impact of volcanic eruptions on *plant cultivation* is due to two main factors: (1) a decline in incoming solar radiation that results in dramatic yield decreases by cooling and reducing photosynthesis; and (2) ash settling on agricultural plots. *Settling ash* causes plants to decay or retards their growth by various causes (damage to plants under the weight of the ash, chemical injury, and reduced input of solar radiation needed to support photosynthesis).

The impact on *animal husbandry* is related mainly to poisoning of animals eating ash-contaminated forage. The hazard for *electric power transmission* is due to the additional load of ash that has settled on wires and supports. Challenges for *residential buildings* are also connected with excessive weight of ash on roofs, clogging and destruction of gutters, clogged sewage systems, etc. It was settled ash (up to 3 m thick) that ruined Pompeii on 24 April AD 79.

Volcanic gases are dangerous for people, vegetation, and animals and may cause acid rains. The effects on vegetation are connected primarily with acid rains of eruptive origin. Volcanic gases pose certain problems for *air transportation*. For example, after the eruption of El Chichon in 1982, aircraft companies began to receive complaints about very rapid degradation of cockpit glass which became coated with a network of fine cracks, dramatically reducing visibility. A reason for this cracking was sulphur compounds (Bernard and Rose 1990). It is estimated that the El Chichon eruption released approximately 20 million tons of sulphuric acid into the atmosphere (Vysotsky 1997).

The hazards of *lava flows* are related to the high lava temperatures often resulting in fires, the huge mass crushing through walls, and other impacts on structures. The flow rate depends on the type of lava, viscosity, slope grade, intensity of flow, and form of the jet. The 65 km/h speed on Surtsey Island in Iceland is considered to be a world record (Kukal 1985). The speeds of the most viscous lavas are measured in centimetres per hour. Lava flows are most dangerous to things, such as residential buildings, highways, and power transmission lines.

Burning volcanic clouds are composed of a mix of volcanic gases with tephra. The inner temperatures reach 700–1,000°C; that is why, in spite of the short duration of their effects, they usually result in death due to burns and suffocation. Apart from high temperatures, which cause fires, their destructive effects result from enormous pressure on the walls of structures due to the considerable density and speed of displacement.

Volcanic mudflows (lahars) occur when ash is soaked with water. They affect the following human activities and structures: (1) agriculture (annihilation of farmland); (2) residential buildings (demolition of buildings and other structures by direct impact of the moving mass and burial with rock debris); and (3) transportation (destruction of roads, automobile and railway bridges, etc.).

At present, the average annual *mortality* from volcanic eruptions is about 800 persons, and economic losses amount to US$800–900 million (Govorushko 2007b).

People have used various ways to protect themselves and their property from volcanic activity. To avoid danger, they dug a *canal* on the slope of Etna and made a barrier to form a new lava course. On the slope of the Kelut volcano (Java) in 1905, they erected a *dam* for protection from lahars (Suprunenko 1999). As early as 500 years ago, in North America close to Mount Rainier, a *reservoir* was built to prevent the progress of lava streams. On the slope of Vesuvius, farmers constructed low stone walls to protect against mudflows.

A more modern method is *bombing* from the air to destroy volcano cone walls around the vent to make the lava flow in the desired direction. This method was, in particular, used to change the direction of the lava stream during the eruption of Mauna Loa volcano near the town of Hilo in the Hawaiian Islands. *Rinsing lava streams with water* as a means of protection has been practised for a long time. With this method, the lava's viscosity increases, and the lava stops moving.

Volcanoes may sometimes be of *advantage* to people. Extinct volcanoes provide favourable sites for installation of *radio telescopes,* because crater walls extinguish radio noise. Volcanic craters are also used as *water storage tanks* to accumulate water during rainy periods. To prevent water from seeping into the soil, the crater is covered with a special plastic. Such a reservoir of 822,000 m³ was made on Tenerife Island, Canary Archipelago. An extinct volcano near Granada (Nicaragua) has been used for 20 years for *storing industrial and domestic waste* for the entire region (Kranz 2003). Not infrequently, volcanic ash is used to manufacture *construction materials*. For example, a considerable amount of ash, precipitated in 1973 during the eruption on the Icelandic island of Heimaey, has been exported to Norway to produce light, porous concrete fillers.

Different aspects of impacts of volcanic eruptions on human activities are illustrated by Photos 1.6–1.10.

Photo 1.7 Lava blocking Highway 130 on the south-western coast of the island of Hawaii (United States) on 21 February 1990. During multiple eruptions of Kilauea volcano in 1983–1998, lava flows blocked nearly 13 km of the highway to depths of about 25 m. The total territory buried was 99.7 km^2 (Photo credit: J.D. Griggs, Hawaiian Volcano Observatory, U.S. Geological Survey)

Photo 1.8 Burning volcanic clouds are a mixture of volcanic gases and tephra. Their destructive effects are caused by high temperatures that lead to fires and by high pressure due to considerable density of clouds and high speeds of their displacement. This photo shows the ruins of a house in the village of Francisco Leon, south-eastern Mexico, destroyed by the burning volcanic cloud during the El Chichón volcano eruption from 29 March to 4 April 1982. The reinforcing concrete bars in the ferroconcrete wall are bent in the direction of the burning cloud movement. Several clouds of this kind moved in different directions 2–8 km from the volcano. Besides the village of Francisco Leon, which is situated 5 km from the volcano, eight more villages were destroyed. More than 2,000 died (Photo credit: U.S. Geological Survey, photo by R.I. Tilling, 1 June 1982)

Photo 1.9 Volcanic mudflows (lahars) appear when water-sodden ash glides down volcanic slopes. The photo shows a lahar-damaged house after the eruption of Mount St. Helens (United States) which occurred on 18 May 1980 at a distance of 40 km from the house. The mud coatings on trunks indicate the top level of the lahar. Numerous lahars destroyed approximately 200 buildings, pulled down 44 bridges, coated 200 km of auto routes and 27 km of railroads with sediments, and killed 69. Several mudflows travelled over distances of 60–100 km (Photo credit: U.S. Geological Survey, photo by D.R. Crandell, 1980)

Photo 1.10 Volcanic eruptions oftentimes bring about climatic changes. Voluminous ash eruption fogs the atmosphere and thus decreases temperatures. The photo shows the eruption of the Lascar volcano in northern Chile on 19 April 1993. Schools as far as 190 km away were closed due to fallout from the eruption (Photo credit: University Corporation for Atmospheric Research, photo by Caspar Amman)

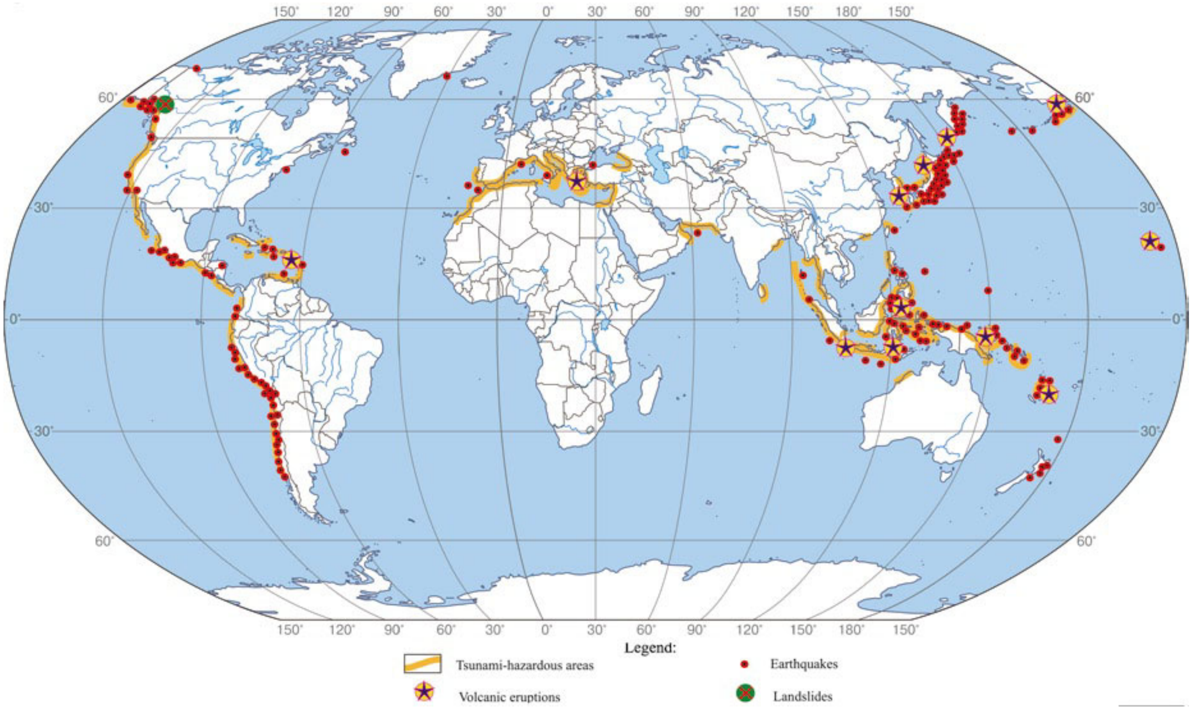

Fig. 1.3 Coastal regions most subject to tsunamis. Compiled by the author with the use of the Tsunami Catalogue (http://www.ngdc.noaa.gov/nndc/struts/form?t=101650&s=70&d=7). All known events with wave heights greater than 4 m are shown

1.1.3 Tsunamis

Tsunamis are sea gravity waves of great length that are created chiefly during submarine earthquakes as a result of extensive bottom area shift (upward or downward).

Tsunamis are a rather common phenomenon by sea coasts (Fig. 1.3). According to N.A. Schetnikov (1981), their *distribution* in the oceans is as follows: Pacific, 75%; Atlantic, 21% (including 12% in the Mediterranean Sea); Indian, 3%; and the Arctic, 1%. The coastal regions of Japan, the Hawaiian Islands, the Aleutian Islands, Alaska, the Solomon Islands, the Philippines, Indonesia, Chile, Peru, and New Zealand in the Pacific Ocean as well as the seaboards of the Aegean, Adriatic, and Ionian Seas in the Mediterranean region most often suffer from these waves.

Tsunamis may be caused by the following *events*: (1) earthquakes; (2) volcanic eruptions; (3) rockfalls; (4) landslides; (5) submarine landslides; (6) submarine explosions; and (7) meteorological phenomena.

Submarine earthquakes are the most frequent cause of tsunamis. According to some data, they account for 90% of such events (Seismic dangers 2000). However, not every submarine earthquake causes a tsunami. They occur only when the earthquake centre is at certain depths (earthquakes at depths over 50 km usually do not cause tsunamis) and is having a certain mechanism. It is believed that vertical dislocation of the sea bottom is required (Gere and Shah 1988).

Volcanogenic tsunamis emerge due to volcanic explosions. The caldera that forms immediately becomes filled with water, causing a long, high wave.

Rockfalls and landslides (both under water and above water) that lead to tsunamis are, in their turn, usually caused by earthquakes. The most well-known case of a tsunami caused by slides took place on 9 July 1958 in Alaska; the tsunami was caused by falling ice and rock of a total volume of about 300 million cubic metres from a height of nearly 900 m from the Lituya Glacier into the bay of the same name. The wave surge was as high as 530 m (Natural-anthropogenic processes and environmental risk 2004).

An example of a tsunami caused by *submarine landslides* is the December 1951 tsunami on the coasts of Puerto Rico and Barbados; this tsunami emerged on the slope of the ocean basin at Puerto Rico during a calm period with a complete absence of seismic shocks (Kononkova and Pokazeev 1985).

A tsunami caused by an *underwater nuclear explosion* with a Trotyl equivalent of 20,000 ton took place in 1946 (Vlasova 2004).

Meteorological tsunamis are caused by sudden fluctuations of atmospheric pressure. Such phenomena were observed in Nagasaki Bay (Japan), not far from the Kuril Islands; the port of Longkow (China); and the Ciutadella harbour (Menorca Island, Spain) (Rabinovich and Monserrat 1996).

The *destructive power of a tsunami* depends on the following *factors*: (1) the depth of the centre of the earthquake or eruption (the less the depth, the more powerful); (2) the centre's dimensions; (3) water layer thickness (the thicker, the more powerful); (4) an earthquake's strength or the mass of fallen rock; (5) the distance from the place where the tsunami originates to the shore; (6) the bottom and shore relief features on the way of the wave's propagation (the less the slope, the stronger the wave); and (7) the configuration of the coastline (the most dangerous are taper bays and straits) (Govorushko 2008b).

The basic parameters of a tsunami are the following: maximum propagation speed, 800–1,000 km/h; wave's maximum length, 200–300 km; maximum height in the open sea (5 m; maximum surge height, 70–80 m); and maximum period, 2.5–3 h.

The *speed* of a tsunami is closely connected with the depth. For example, if the wave's speed at a depth of 4,000 m is 720 km/h, at more shallow points, it will decrease as follows: 1,000 m, 360 km/h; 720 m, 160 km/h; 50 m, 80 km/h; and 10 m, 36 km/h (Seismic dangers 2000).

Contrary to widespread opinion, a tsunami is *not a single wave, but rather several waves* (usually three or four). The maximum surge height is, as a rule, typical for the second or the third wave. As a tsunami's height is closely connected with hydrography, its value may greatly differ even in neighbouring areas.

The *reasons for damage* caused by tsunamis are as follows (Gere and Shah 1988): (1) flooding due to the quick rise of the sea; (2) dynamic loads on structures; (3) impacts by drifting wreckage; (4) soil washout at foundations caused by the fast water; (5) fluctuations of water level (leading, first of all, to damage of moored vessels); and (6) dynamic impact of the air wave in front of the tsunami.

Tsunamis cause considerable mortality and influence a number of objects and types of human activity, such as the following: (1) residential and industrial buildings; (2) water transport; (3) agriculture; and (4) forestry.

Of the six listed factors of a tsunami's impact, mainly the first three lead to *human deaths*. In each case, any of them may come to the forefront. Sometimes, people drown because of the fast *water rise*. In other situations, they perish mainly due to the *destruction of residential buildings*, particularly if the tsunami occurred at night. Sometimes, the main reason is *impacts of drifting wreckage* if the coastal territory is littered with various objects. In that case, objects and equipment that are thrown and carried away by the water stream may cause high mortality. For example, during the 1 January 1996 tsunami in Indonesia and the 17 July 1998 tsunami in Papua New Guinea, practically all human deaths were caused by concussions caused by other objects moving in water at high speeds (Seismic dangers 2000).

An analysis of *mortality* and *economic loss* due to tsunamis in the twentieth century enabled us to estimate the average annual mortality at 100–150 people and the economic losses at US$100 million (Govorushko 2003). Per these figures, tsunamis cause far less destruction than their nearest 'relatives' – earthquakes and volcanic eruptions. However, the most destructive tsunami in the history of mankind, which occurred in the Indian Ocean off the north-west coast of Sumatra on 26 December 2004, made us revise this concept to a great extent. As a result of this tsunami, 294,743 people from 55 countries perished or were missing, more than five million people were wounded, and about one million people found themselves homeless (http://tsun.sscc.ru/tsulab/20041226fat_r.htm).

The impacts of tsunamis on *residential buildings* are typical enough. The main factors are *dynamic wave loads* and *impacts by drifting wreckage*. The minor factors are *flooding* and *washout of soil* from under foundations (Govorushko 2009c).

Photo. 1.11 Dynamic impact of waves is one of the crucial destructive factors of tsunamis. The magnitude 9.2 earthquake of 27 March 1964 generated a wave, 31.7 m high. The photo shows a 5.2 by 31 cm plank in a truck tyre in Whittier, Alaska. In this area, the waves destroyed two sawmills, a tank farm, a wharf, a railroad depot, and several buildings (Photo credit: U.S. Geological Survey)

Photo 1.12 Water transportation is one of the realms that suffer badly from tsunamis. The impacts of tsunamis on water transportation are mainly exerted through impacts of dynamic waves and water level fluctuations that damage berthed vessels. The photo shows a fishing boat configured for catching squid that was beached high by a tsunami surge at Okushiri Island. Next to it, a fire engine is located. (Photo credit: U.S. National Geophysical Data Center, photo by D.J. Sigrist, International Tsunami Information Center, Honolulu, Hawaii, 12 July 1993)

Photo 1.13 Tsunamis rarely impact railroad transportation directly. A railway accident near Hikkaduwa Station, the south-east coast of Sri Lanka, became one of the consequences of the calamitous tsunami of 26 December 2004 in the Indian Ocean (Photo credit: S.S.L. Hettiarachchi, University of Moratuwa, Moratuwa, Sri Lanka)

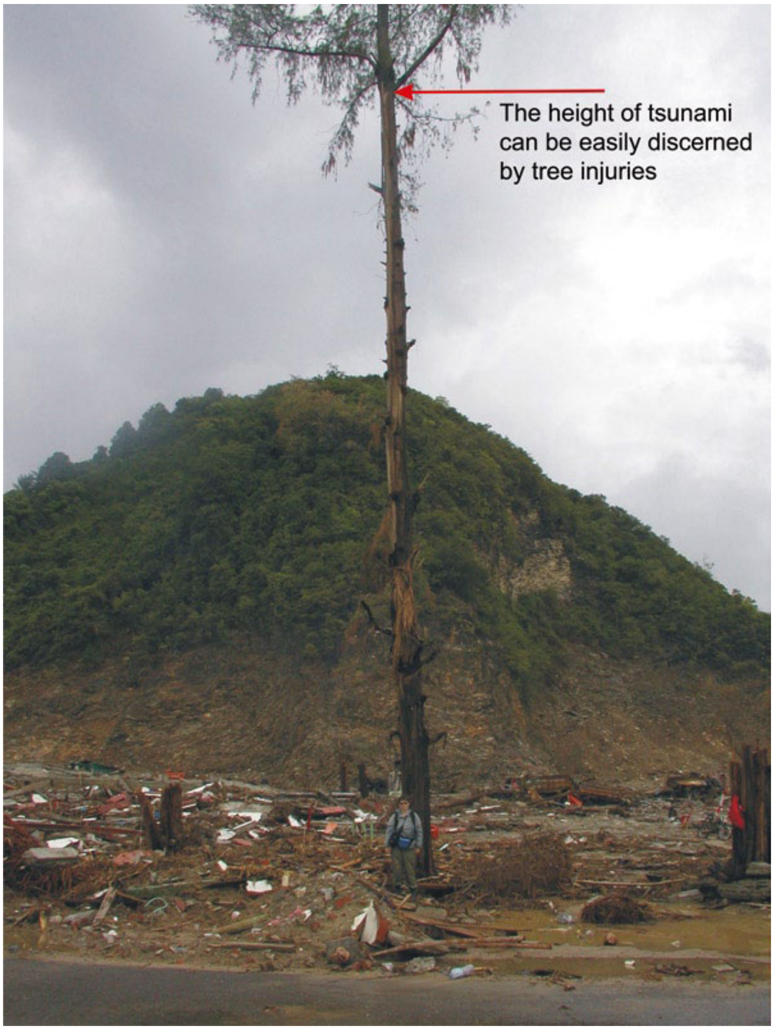

Photo 1.14 The heights of tsunami waves from the same earthquake within different sections of the seacoast can differ greatly. Apart from the distance from the origin point to the coast, they depend on the coastline configuration (the narrowing bights and straits are most dangerous), bottom relief on the wave way (the smaller the inclines, the greater the heights), and other factors. In the course of the catastrophic tsunami on 26 December 2004 in the Indian Ocean, the heights of waves reached 34.9 m along the Sumatra north-western coast. However, near the town of Banda Aceh, it was ‘only’ about 16 m. The height of ‘uprush’ can be judged from broken branches (Photo credit: T.K. Pinegina, Institute of Volcanology, Petropavlovsk–Kamchatsky, Russia, January 2005)

Photo 1.15 On 1 September 1992, an earthquake with a magnitude of 7.0 generated a tsunami with waves between 8 and 15 m high that struck 26 towns along 250 km of Nicaragua's Pacific coast. This photograph shows the tsunami damage at El Tranisto (population of 1,000), the area most devastated by the tsunami in Nicaragua. Sixteen people were killed, and 151 were injured. More than 200 houses (nearly all the houses in El Tranisto) were destroyed by waves that reached more than 9 m at this site (Photo credit: National Oceanic and Atmospheric Administration)

Tsunamis commonly influence *water transport* also. Here, of cardinal significance are the *dynamic impact of waves* and *water level fluctuations*. In the first case, vessels are thrown ashore; in the second, moored ships are damaged.

The effects on *agriculture* and *forestry* are connected with *flooding* and the *dynamic impact of waves*. Due to waves' strokes, soil becomes covered with sand and silt, and woodlands and fruit plantations are destroyed. Arable lands become worthless, and crops perish due to water salinity, but salinity has less importance because of the comparatively short duration of the flood.

Different aspects of impacts of tsunamis on human activities are illustrated by Photos 1.11–1.15.

1.2 Cryogenic Processes

Cryogenic processes are those that take place in freezing and thawing rocks and in permafrost rocks under conditions of changing temperatures and the rocks' transitions through the melting of ice.

The area of *distribution* of cryogenic processes is considerable (Fig. 1.4). The area of the cryolithozone (permafrost zone) of the Earth is 38.15 million km^2, which corresponds to 25.6% of the land surface, and 21.35 million square kilometres fall in the northern hemisphere. Permafrost underlies 20–25% of Earth's land area, including about 99% of Greenland, 80% of Alaska, 50% of Russia, 40–50% of Canada, and 20% of China. Seasonally frozen rocks are more widely distributed. They occupy vast territories with the exception of regions with tropical and subtropical climates.

The *number* of cryogenic processes is quite high, but among them the most significant processes, from the viewpoint of influence on human activities, are frost swelling, thermokarst processes, thermal abrasion, thermal erosion, cryogenic cracking, and solifluction.

1.2.1 Frost Heaving

Frost heaving is a rising of the soil surface caused by an increase in its volume in the course of freezing due to the spreading of particles by growing ice crystals. The *intensity* of the swelling depends on the degree of water saturation, and it is especially high when the moisture content increases through inflow from neighbouring areas.

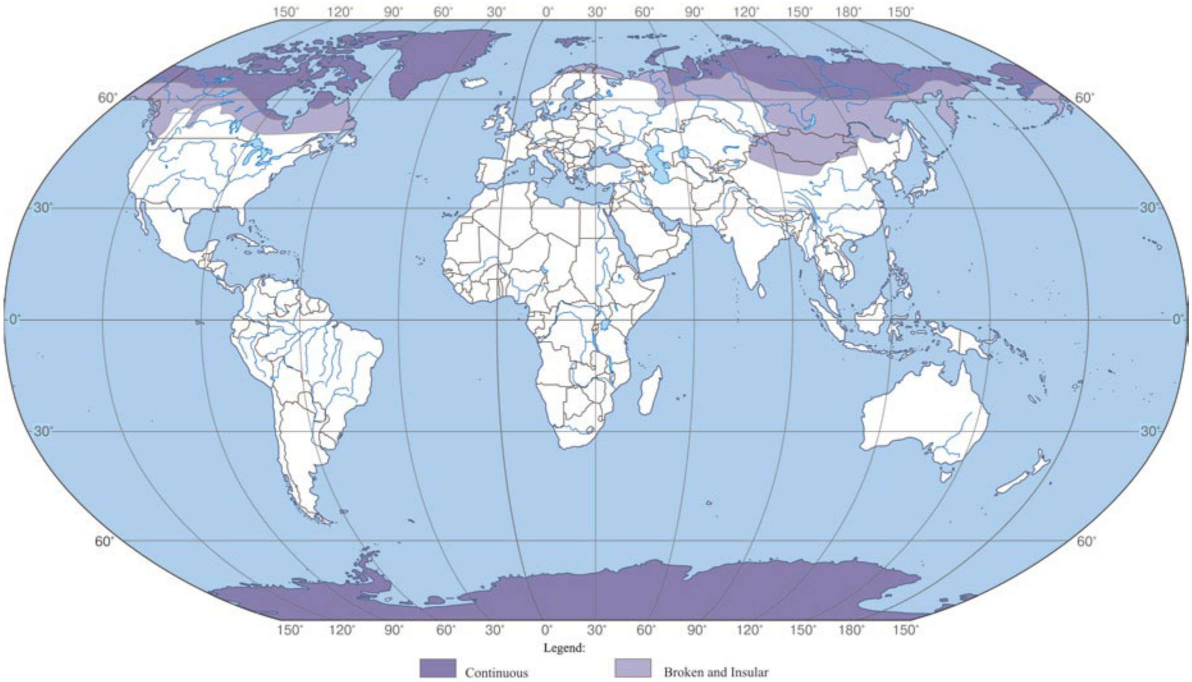

Fig. 1.4 Distribution of permafrost (Resources and environment 1998. Reproduced with permission of the Institute of Geography of the Russian Academy of the Sciences)

In determining the *mechanism* of the influence of frost heaving on engineering facilities, the tangential and normal forces of a swelling are identified. When freezing occurs near the foundation, the ground freezes to its side face. The swelling forces tend to move the foundation up, together with a layer of frozen ground. If the forces of ground freezing with the foundation are less than the mass of the structure, then the frozen layer moves relative to the foundation. The shear strength of the foundation when it freezes along with the ground determines the *tangential forces* of swelling.

When a frozen layer increases in thickness, the force of ground freezing with the foundation can exceed the load resistance. In this case, there will be 'bulging' of the foundation; that is, its heave, together with the ground will result in loss of stability and normal operation of the structure. The normal swelling forces act at right angles to the foundation. The straight freezing of the swelling ground near the side faces of a foundation results in their all-round pressurization. When this occurs, a swelling nonuniformity can lead to one-sided pressure and horizontal displacement. The soil freezing under a foundation determines the development of *normal forces of swelling* at its foot.

Under the action of the forces of frost ground heaving on a foundation, secondary stresses arise in the bearing members of the structure and result in *deformations*; these deformations can disturb the normal operation of the building or make it unusable. Deformations can cause the formation of cracks in foundations, ceilings, floors, and walls and skewing of door and window openings. These deformations have a cyclic, seasonal nature and repeat every year. During the spring melting of swelling ground, water permeability and compressibility increase, while the carrying capacity decreases, which results in differential settlement of a building.

Frost heaving represents a danger for *motor roads* and *railroads* and for *airfields,* causing disruptions in their continuity and evenness. These disruptions, in turn, can lead to emergency conditions in transport due to pushes and strokes in the course of its motion (bursting of rails, automobile accidents, and aircraft accidents on take-off, etc.). In Norway, 300 km of railroads go out of service due to frost swelling every year. In the United States, the railroads in the states of Wisconsin, North Dakota, Nebraska, and Idaho are affected, to the maximum extent, by this phenomenon (Geocryological dangers 2000).

Photo 1.16 Pingos emerge in areas of permafrost or seasonally frozen ground due to non-uniform ice formation within the ground. Long-term pingos appear in the course of frost penetration into thawed grounds, usually below lakes, should the lake grow shallow or completely dry up. The largest pingos reach 50 m high and 600 m in diameter. The photo shows pingos near Tuktoyaktuk, Northwest Territories, Canada (Photo credit: Emma Pike)

Photo 1.17 Mounds of heaving ground do not have considerable impacts on humans since the lands where they occur are usually sparsely inhabited and poorly developed. The photo shows mounds of heaving ground on the Tynda–Zeysk section of the Baykal–Amur Railroad, Russia (Photo credit: V.S. Afanasenko, Department of Geocryology, Moscow State University, Russia)

Photo 1.18 The photo shows a wall collapse in a dwelling in Yakutsk, Russia, caused by thermokarst. Nobody was injured. To prevent such collapses, houses must be built on piles. Thereby, the air space under the house should prevent the heat impact on the frozen ground. This house was erected 'low-sitting', and for the long time it was occupied, the air space became stuffed with finely dispersed material. This led to gradual melting of frozen grounds lying below (Photo credit: Y.A. Murzin, Institute of Permafrost Studies, Russian Academy of Sciences, July 1993)

Frost heaving also constitutes a certain danger for *communication and transmission lines, bridges,* and other structures. The centre of one of the bridges in the Alaskan Railroad rose by 35.5 cm during the winter of 1952–1953. In order to replace the rails in their original position, the upper piles had to be cut (Anderson and Trigg 1981).

Swelling is a primary cause of underground *pipeline* deformation, especially where the pipes cross rivers. So, in November 1972 through January 1973, a pipe break at a weld accompanied by a gas release happened as a result of frost swelling in a section of the Messoyakha-Norilsk pipeline where it crossed the Yenisei River (Atlas of natural and technogeneous dangers and risks 2005).

Frost heaving also has adverse effects on *grassland farming* and *crop production*. During freezing, the soil (especially loose soil) is slightly raised, and as a result, the roots of plants are detached. After melting, the soil subsides and plants with detached roots remain under the sun and wither.

To some extent, frost swelling also adversely affects *hydropower engineering*. The straight freezing of clayey dam cores results at times in destruction of their watertight integrity (Natural-anthropogenic processes and environmental risk 2004).

In regions where permafrost is present, perennial mounds caused by cryogenic heaving (pingos) are abundant. Since they are observed in less developed regions of the world, damage related to them for the present is not great.

The effects of frost swelling on human activities are illustrated by Photos 1.16 and 1.17.

1.2.2 Thermokarst, Thermoerosion, and Thermoabrasion

The term *thermokarst processes* means a melting of ground ice accompanied by strain in beds (initiation of subsidence and depressions or formation of cavities in these beds).

Thermokarst constitutes a serious danger to the safety, stability, and normal operation of structures (*railroads, motor roads, pipelines, buildings,* etc.). For example, in the summer of 1984, subsidence of

Photo 1.19 Thermokarst poses a formidable threat to railroad maintenance. The photo illustrates the numerous deformations of the Northwestern Railway near Strelna, 75 miles northeast of Valdez, Alaska (United States). The thermal equilibrium of the fine-grained sediments underlying the roadbed was disrupted during construction, and the permafrost started to thaw differentially. Maintenance and use of the railroad were discontinued in 1938. Subsidence, as well as lateral displacement, has continued (Photo credit: U.S. Geological Survey, September 1960)

the Tynda-Berkakit village railroad body base near the village of Magot, Russia, took place due to thawing of ice-saturated ground. As a result, the rail track was destroyed, and a train was derailed (Atlas of natural and technogeneous dangers and risks 2005). Practically, all the buildings erected in Magadan oblast (Russia) prior to 1951 (when they were constructed without regard for the frozen subsoil properties) were deformed due to ground bearing capacity failure as a result of thawing (Russian Arctic 1996).

The cause of damage to the buildings was generally the formation of a thawing basin, resulting in irregular settlement of foundations and, as a consequence, initiation of cracks, subsidence of quoins, warping of door frames, etc. Thermokarst subsidence deforms the beds of *motor roads* and *railroads* and surface and underground *pipelines,* frequently resulting in accidents.

The term *thermoabrasion* means a process of destruction of shores composed of perennially frozen rocks or ice due to the heating effects of water. Thermoabrasion (thermal abrasion) is an important process in forming the shores of Arctic seas (primarily in Russia, the United States, and Canada). Distribution of thermoabrasive shores is shown in Fig. 1.5.

The *basic process* of thermoabrasion is a washout of the underwater shoreface under the action of roughness and currents. It results in the formation of a niche, and further deepening causes frozen rock blocks to fall. The rate of thermoabrasion depends on the lithologic composition (the likelihood of washing out of rocks increases in the following order: clays, loams, clay sands, sands) and the ice content in the rocks (the greater the ice content, the higher the erosion rates).

The *rates* of shore retreat in the case of *marine thermoabrasion* range from 0.2 to 8 m/year. The total value of thermoabrasion for the Russian segment of the Arctic is estimated at 338 million tons per year; this much sediment comes to the coastal zone, owing to thermoabrasion (Stolbovoi 2002). The volume of deposits entering the Laptev Sea due to washout of the islands in the Lena River delta reaches 1.8 million tons per year (Grigoriev and Schneider 2002). A number of

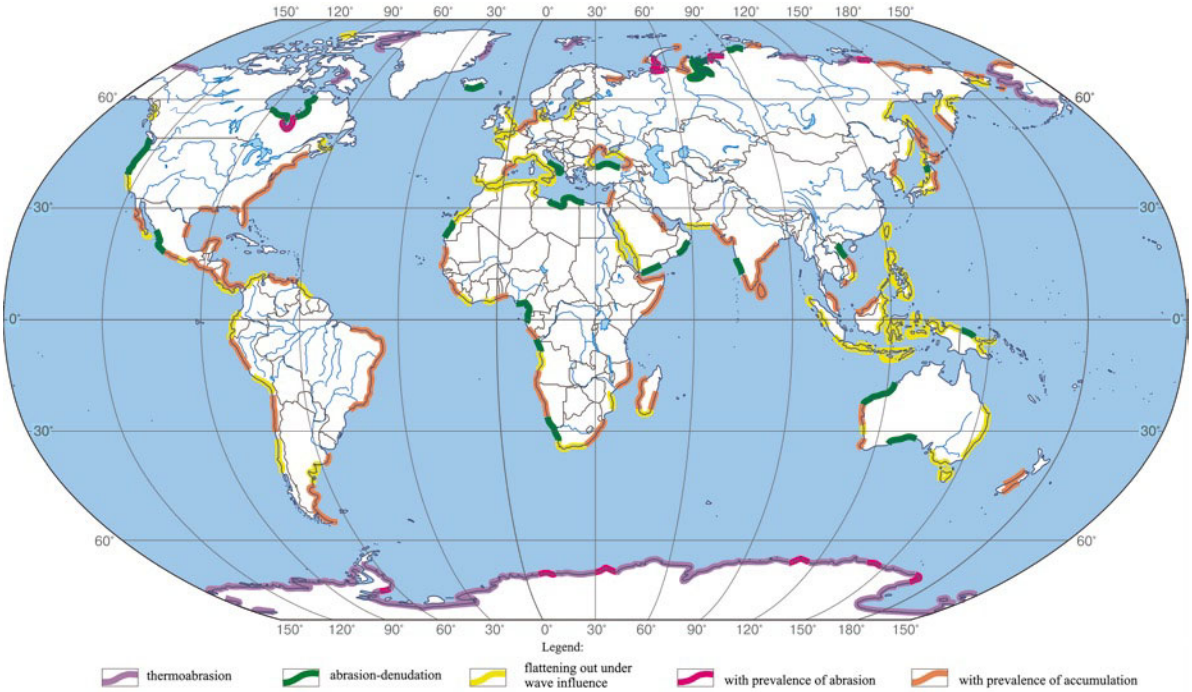

Fig. 1.5 Distribution of thermoabrasive, abrasive, and accumulative shores (Shores 1991. Reproduced with permission of Moscow State University, Russia)

in situ observations have been aimed at estimating the losses of land. So, according to data of J. Brown and J. Jorgenson (2002), an 11-km sector of the shore near Barrow (north-western Alaska) lost 28.2 ha during a period of 50 years.

Long-term average annual rates of *lake thermoabrasion* are frequently 2–10 m/year. The intensity of land elimination on inland water bodies may also be extremely high. For example, over 25 years of the Bratsk Reservoir (Russia) storage operation, thermoabrasion has destroyed about 270 km^2 of the coast (Theoretical principles of engineering geology 1985). Here, events of extremely high intensity were recorded. So, in 1962–1967, the shore retreated by 759 m near the Artumei settlement, and the erosion rates reached 435 m/year and 150 m/day (Myagkov 1995).

Thermoabrasion affects the following *kinds* of human activity: (1) industrial and civil site development; (2) water transport; (3) pipeline transport; (4) mineral resource industry; (5) hydropower engineering; and (6) agriculture.

The effects on *site development* are expressed as a threat to beach installations. In September 1986, a sharp intensification of thermoabrasion on the Alaskan coast of the Chukchi Sea took place as a consequence of two storms. The boroughs of Barrow and Wainwright experienced serious losses. In the first settlement, 152 people were evacuated and, later, 32 houses were transported to a new site (Walker 2001). Several power transmission line poles also had to be moved and, in addition, the storm damaged an archaeological monument: peat houses (Walker 1991).

Effects on *water transport* involve changes in navigation conditions. Thermoabrasion processes result in a reduction in depths and create problems for shipping. Water transport is also affected by the demolition of lighthouses and navigation markers. In addition, thermoabrasion causes problems where *underwater pipelines* make landfall. The influences of thermoabrasion on the *mineral resource industry* are rather positive and lie in the fact that, to a large degree, it forms offshore placer deposits of minerals.

The impact on *hydropower engineering* lies in the fact that thermoabrasion creates an abundance of solid particles. This causes the sedimentation of reservoirs

Photo. 1.20 The average rate of thermoabrasion does not exceed 0.5–1.0 m/year; however, it may become as high as 10 m/year. Coastal retreat occurs mostly during 2–3 summer months; the process dramatically intensifies at times of heavy storms. The photo shows the coast of the Chukchi Sea in Alaska, near the Wainwright settlement. The severe storm of October 1986 exposed ice wedges, and by that, speeded up coastal destruction which imperilled dwellings (Photo credit: H.J. Walker, July 1987)

and reduces their usable storage. When woody and peaty shores are destroyed, there is also clogging of waterways and chemical pollution. The effects on *agriculture* are expressed as the destruction of croplands and grazing lands; however, considering the small scales of this kind of human activity in the regions subjected to thermoabrasion, the effects are considered to be minor.

Thermoerosion is a process that causes the break-up of frozen rocks. Simultaneous thermal and mechanical actions of water flows result in intrusion of the water flow into the frozen mass, with the formation of furrows, ruts, and cavities.

Thermoerosion is initiated where the vegetation cover is discontinuous, which can be caused by both natural factors (frost crack formation, solifluction, slip-outs, etc.) and anthropogenic factors. For thermoerosion to develop, the following conditions are necessary (Dynamic geocryology 2001): (1) presence of perennially frozen ground; (2) a grade of more than 1.5°; and (3) sufficient rainfall intensity. The *intensity* of gully erosion is high. Elongation of gullies occurs at rates of 1–2 to 5–7 m/year, reaching, in some cases, 20–30 m/year, while, within ravines and hollows, they can be up to 100–150 m/year.

Thermoerosion is subdivided into two *types*: bed and gully. The mechanism of *bed thermoerosion* is, to a large extent, similar to that of thermoabrasion. When a shore is being undercut, thermoerosion niches are formed, followed by the fall of blocks. When *gully thermoerosion* develops, gravitational failures result in blockages in channels and, as a consequence, intense cutting and detachment of sides. Riverbed thermoerosion affects different installations located within the coastal zone (harbour installations, transmission and

Photo 1.21 The nature of riverbed thermoerosion is, in many ways, similar to that of thermoabrasion. Coastal cut-down forms thermoerosion niches, after which, large blocks fall down. The photo demonstrates the process of coastal destruction in the Colville River delta, Alaska (United States) (Photo credit: H.J. Walker, 21 June 1966)

communication lines, roads, pipelines, and other structures). H.J. Walker (2001) uses as an example the thermoerosion effects on the Nigilik village in the Colville River delta (Alaska, United States). From 1949 to 1986, a shore retreated there by more than 50 m, and a threat of one house failure appeared. In order to prevent the destruction, the house was transported over a distance of 30 m from shore.

The effects of thermokarst processes, thermoabrasion, and thermoerosion on human activities are illustrated by Photos 1.18–1.22.

1.2.3 Cryogenic Cracking and Solifluction

Cryogenic (frost) cracking is a dissection of a frozen rock mass with cracks that develop when temperatures fall. It occurs in regions of both permafrost and seasonally frozen rocks. The cracks form during the fall through winter period. They are most pronounced in areas with an acutely continental climate and insignificant snow depths. The *widths and depths of cracks* depend on the composition of the rocks, their uniformity, and temperature distribution. Their maximum

Photo 1.22 Thermoerosion also intensifies in cases of human-related breaching of vegetation cover. The construction of a pipeline and parallel power line triggered thermoerosion processes along the pipeline, which threatened the balance of power transmission towers (Photo credit: A.N. Kozlov, Department of Geocryology, Moscow State University, Russia)

lengths reach tens and hundreds of metres, while depths are 5–6 m. The widths of cracks at the top are generally 2–4 cm, though cracks more than 10 cm wide occur.

Frost cracking constitutes a certain danger for the following engineering *structures*: (1) motor roads (roadways may go over the discontinuity); (2) residential and industrial buildings (breakage of continuous footings, cracks in the walls); (3) airfields (damage to airfield pavements); (4) pipelines (deformations and even breaks of underground steel pipelines); and (5) underground communication cables.

Solifluction is a slow viscous plastic flow of thawing waterlogged soils and fine-dispersed ground on gentle slopes. It occurs in Russia, the United States (Alaska), Canada, Norway (especially on the Svalbard Islands), the Falkland Islands, and mountain regions of central Asia.

The *conditions* necessary for the development of solifluction include the following (Romanovsky 1993): (1) increased content of pulverescent particles, (2) increased humidity, (3) presence of surface slopes (usually 2–3 to 10–15°), and (4) absence of woody and large shrub vegetation.

Photo 1.23 Cryogenic cracking is generated by stretching strains developing in frozen ground. In spring, water from melting snow penetrates into the ground and freezes. Repetition of the process leads to cavern-load ice formation. The photo shows polygon wedge ice (and melting pingo) near Tuktoyaktuk, Northwest Territories, Canada (Photo credit: Emma Pike)

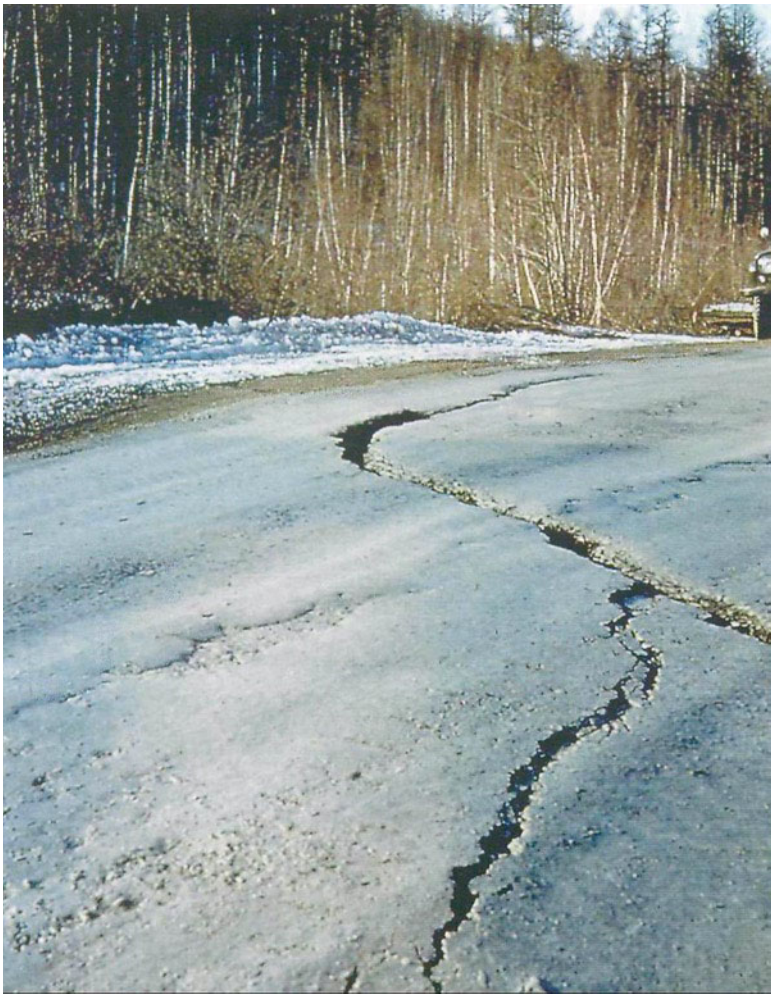

Photo 1.24 Cryogenic cracking oftentimes creates problems for auto road and railroad exploitation. The photo shows frost-induced cracks that deform a roadbed in Zabaikalye, Russia (Photo credit: S.Y. Parmuzin, Department of Geocryology, Moscow State University, 1967)

Photo 1.25 A feature of differential solifluction is generation of micro- and mezo-landforms that are conditioned by different velocities of shifting of melting ground on different spots of the slope. At times, the speed of this kind of solifluction can reach 10 cm/day, but customarily it does not exceed 10 cm/year. The photo shows solifluctional flows near Suslositna Creek, Alaska (United States) (Photo credit: U.S. National Geophysical Data Center)

A *distinction* is made between mantled and differential solifluction. For the former, relative areal uniformity, low drift velocity (2–10 cm/year), and an absence of sinter relief forms are characteristic. The distinctive feature of *differential solifluction* is the presence of characteristic forms of micro- and mesorelief: solifluction 'tongues', flows, strips, terraces, etc. Their formation is caused by differences in drift velocities of thawing rocks on different parts of a slope. The rate of this type of solifluction may reach 10 cm/day. The areas of the solifluction relief forms range from several square metres to thousands of square metres.

One kind of solifluction is the *slip-out* (so-called fast solifluction). It is characteristic of steeper slopes (not less than 10°) formed by silt sandy loams or clay loams; fast solifluction has a catastrophic character but develops within relatively small areas. In the case of fast solifluction, rates reach tens of metres per day (Geocryologic dangers 2000).

The influences of fast and slow solifluction are most urgent for the following *kinds* of human activity: (1) mineral resource industry; (2) transport (motor, rail, pipeline); and (3) industrial and civil engineering.

Photo 1.26 A slip-out (so-called fast solifluction) is one kind of solifluction. It is characteristic of the steeper slopes formed by silty loams or sandy clays. Rates reach several tens of metres per day. The photo shows solifluction slip-out on a bank slope in Yakutia, Russia (Photo credit: V.E. Tumskoy, Department of Geocryology, Moscow State University, Russia)

A negative influence on the *mineral resource industry* is expressed as the *complication of operation* of enterprises due to sloughing of pit walls. Another consequence is *dilution* (reduction in concentrations of the commercial component). During mining operations, rocks containing the commercial component are stored in certain places for the purpose of downstream processing. Grounds that move under the action of solifluction increase the volume of rocks requiring processing, which reduces the economic efficiency of the operation of a mining enterprise. At the same time, slow solifluction has a certain *positive importance* for the transportation of heavy minerals to the valleys of rivers and streams and the formation of *placer mineral deposits*.

The effects on *transport* lie, first of all, in the deformation of hollows in the bodies of motor roads and railroads and complications in the operation of surface pipelines. Problems for *industrial and civil engineering* are similar and consist mainly of sloughing of construction pit walls.

The effects of cryogenic cracking and solifluction on human activities are illustrated by Photos 1.23–1.26.

1.3 Karst

Karst phenomena are initiated in rocks dissolved by natural waters. This process was first studied in detail on the coast of the Adriatic Sea (plateau Karst, which explains its name), not far from the city of Trieste. Territories with manifestations of karst occupy 15% of the Earth's surface (Wilson and Beck 1992). The global karst distribution is shown in Fig. 1.6.

The basic conditions for the *development of karst* are the following: (1) presence of soluble rocks; (2) presence of running waters; and (3) possibility of water circulation. Rocks that are *soluble* in natural waters include limestone, dolomite, chalk, chalky marl, marble, gypsum, anhydrite, rock salt, and others. These rocks vary greatly in solubility. For example, in order to dissolve 1 m^3 of *rock salt*, only 3 m^3 of water is needed, while in the cases of *gypsum* and *limestone*, 1,100 and 80,000 m^3 of water, respectively, are required (Larionov 1974). The solubility of rocks depends also on the *water temperature* and *chemical content* (acids, alkalis, and salts), the *speed* of underground water movement, *rock jointing* characteristics, and other factors.

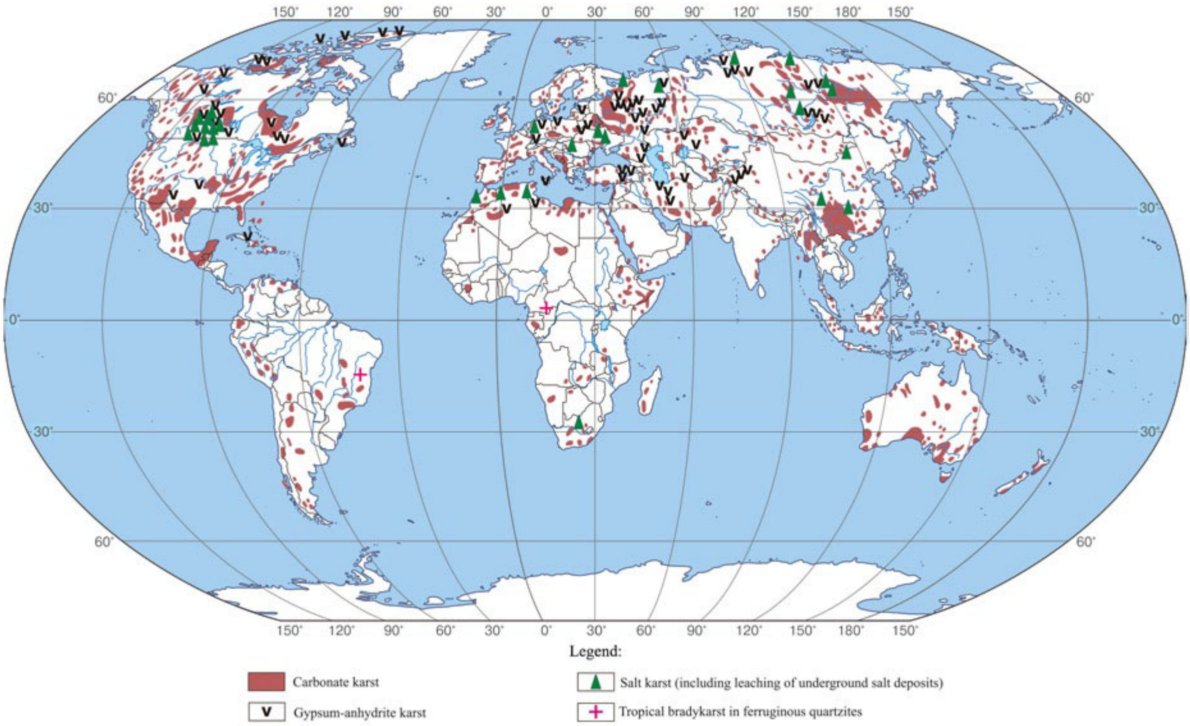

Fig. 1.6 Global karst distribution (Gvozdetsky 1981. Reproduced with permission of Moscow State University, Russia)

Karst deformations can be of catastrophic character (holes), but, more frequently, they are slow subsidence with rates of several millimetres a year. The *sizes* of karst holes can be substantial. For example, a bedding cave measuring 1,275 m long, 1,050 m wide, and 450 m deep was formed in the state of Alabama, United States (Scheidegger 1981). This process has *adverse effects* on the following *kinds* of human activity and structures: (1) transport (rail, motor, air, and pipeline); (2) hydropower engineering (especially reservoir storage); (3) aquaculture; (4) mineral resource industry; (5) residential and industrial engineering; (6) transmission lines and bridges; and (7) crop production.

Effects on *transportation lines* are widespread. Numerous karst holes in the embankment base of the Moscow–Nizhny Novgorod railway periodically have been formed since 1943. Diameters of bedding caves reach 50 m, while their depths reach 10 m (Revzon 1992). The Samara–Zlatoust railway in Russia was constructed in 1889, and as early as 1914, about 460 holes could be counted in its immediate vicinity (Kurbatova et al. 1997). Because of damage near Ufa, a 20-km railway track with three bridges and the station of Kinel needed to be moved to new locations – the most significant disruption (Larionov 1974).

Quite often, karst processes make the construction of *tunnels* difficult. For example, during the construction of a railway from Rome to Naples, Italy, a tunnel was made through Mount Orso, which was formed by chalky limestone (opoka), and the route entered a big cave. The builders were forced to abandon the road and work the adit, bypassing the cave (Exogenous geological dangers 2002).

Quite frequently, negative effects on *hydropower engineering* have occurred. For example, the Mount Hake dam, 72 m in height, was erected in the south of Spain; however, it has not been possible to fill the reservoir because of the presence of karst limestone (Dubljansky and Dubljanskaja 2007).

The influence of karst on *aquaculture* is similar. Various cases of water leakage into karstic rocks that resulted in extensive damage to a fish pond establishment are described by N.A. Gvozdetsky (1981).

The impacts on the *mineral resource industry* consist of complicating the development of a resource or even destroying the deposits. Salina destruction

Photo 1.27 Dimensions of karst deformations can be very large. The largest known sinkhole in the world is a pit up to 662 m deep and 626 m wide with vertical walls. The aerial photo shows sinkholes in Venezuela, Bolívar state. Sima Humboldt is 314 m deep (in the middle part of the picture), and Sima Martel is 248 m deep (in the far background) (Photo credit: Luis Ruiz Berti, 1992)

due to the activation of karst processes has been observed. For example, there was an inrush of cavern waters in the Bereznikovsky potassium pit in Permskaya oblast, Russia, in 1986 due to the formation of a hole measuring 40 × 80 m and more than 150 m deep. As a result, the pit was destroyed, and exploitation of the field was stopped (Exogenous geological dangers 2002).

Cases of karst influence on various *industrial and civil structures* are also numerous. A cave with a diameter of about 50 m formed in December 1962 in a Johannesburg suburb (Republic of South Africa); this event led to the instant destruction of an industrial building and killed 29 people (Legget 1976). In Windsor (Canada), a hole measuring 90 m across and 8 m deep was formed in February 1954, completely ruining two buildings (Woltham 1982). These two incidents are widely known. In the state of Florida (United States), a group of buildings was destroyed (Lotosh 2004), and in the city of Akron (Ohio, United States), a store building was reduced to ruins.

The effects of karst on *housing developments* are recorded more often. Karst processes constitute a serious threat in northwestern Moscow, where, during 1975–2000, 42 sinkholes with diameters of several metres to 40 m and depths of 1.5–8 m were recorded. Events causing the *complete collapse* of several residential buildings are known (Gorshkov 2001). Serious problems are also caused by *smooth karst deformations* of the Earth's surface. They have been observed in the city of Lüneburg (Lower Saxony, Germany), where, beginning in 1949, more than 170 industrial and residential buildings were seriously damaged. Events have also occurred in one of the Paris districts, Ottawa (Canada), the state of Alabama (United States), and other locations (Tolmachev et al. 1986).

The influences of karst on *transmission lines* and *bridges* include reductions in the load-carrying ability of pole footings, which result in the loss of stability of the pillars. There have been many cases of serious damage and even complete destruction of the structures due to collapse of the karst, creating hollows underneath these structures. In one case, a highway bridge was damaged as a result of the failure of the roof of a hollow under the bridge abutments in Alabama (United States) (Lotosh 2004).

The effects of karst on *crop production* are due to increased water filtration in the course of irrigation. For example, the irrigation of rice presents difficulties because of this reason in the karst areas of northern Vietnam; the fields do not remain flooded (Gvozdetsky 1981).

Karst processes also have important *positive* effects on human activities. In the beginning of human civilization, people actively used natural hollows in the Earth's crust – caverns. At present, karst processes have positive effects on the *mineral resource industry*, *recreational activities*, *medical services*, and *water supplies*.

Many *mineral deposits* are closely related to karst caverns. For example, deposits of phosphorites in the

Photo. 1.28 Destruction of buildings is a typical consequence of sinkhole formation. This karst collapse took place on 22 May 1967 in the state of Florida (United States). The sinkhole had dimensions of 156 by 38 m and was 18 m deep (Photo credit: U.S. Geological Survey, 24 May 1967)

Photo 1.29 The effects of karst on auto roads and railroads are also widespread. The photo shows damage to Road 180 due to a sinkhole in the south of Lutherstadt Eisleben, Germany, in 2001 (Photo credit: State Office for Geology and Mining, Saxony-Anhalt, Germany)

states of Tennessee and Florida (United States) provide about 30% of global phosphorus production. In the Lesser and Greater Antilles, in France, and in Germany, deposits of phosphorites are confined to these hollows. Karst hollows are related to deposits of vanadium and lead–zinc ores (Kabwe Mine in Zambia; Otavi and Tsumeb in Namibia), lead–zinc deposits (state of Missouri, United States; Austria; Sardinia island, Italy), and fields of bauxite ore (Jamaica, Haiti, Hungary, France, Romania).

One of the factors leading to the use of karst caves (hollows) for *medical purposes* is the presence of medicinal mineral waters in karst areas of a number of countries. *Other therapeutic factors* include constancy of air temperature; suitable values of humidity; CO_2 content; ions of Ca, Mg, and K; negative electrical charge of aerosols; and the absence of bacteria and different allergens. The caves are extensively used for treatment of different diseases: arthritis, rheumatism, bronchial (spasmodic) asthma, podagra, hypertension, and other conditions.

Recreational uses of caves are of major importance. Mammoth Cave, in the state of Kentucky (United States), is well known in this respect. By 1816, Mammoth Cave had become one of the first American tourist attractions. This is the world's longest cave system, with more than 365 miles explored. The Carlsbad Caverns (New Mexico, United States) and the Luray Caverns (Virginia, United States) are also extensively used for recreational purposes. The number of visitors to the Luray Caverns now is about 500,000 guests each year. This kind of tourism occurs in many countries.

In a number of regions of the world, karst is of prime importance for *water supplies*. The city of Havana (capital of Cuba) is almost completely supplied by karst waters. The role of karst waters in water supplies is also significant in a number of areas of Bulgaria, Romania, Poland, Austria, Switzerland, France, Italy, Spain, Portugal, Hungary, Belgium, Great Britain, and Ireland. The Austrian capital, Vienna, receives 70% of its water from Alpine karst sources (Gvozdetsky 1981).

Karst plays a certain role in some other kinds of human activity. Karst lakes are frequently used for *aquaculture* purposes. Sometimes, they are drained for agricultural purposes. Many caves are used as *enclosures for livestock* and for the storage of *hay*. Quite often, local populations may use caves as *refrigerators*. Sometimes, karst plays a positive role in the course of road laying; for example, the Mas d'Azil cave in the French Pyrenees was used as a 410-m tunnel for municipal road D119 (Relief and humanity 2007).

The *negative impacts* of karst on human activity can be estimated at three to five lives and US$600–700 million a year (Govorushko 2008a).

The effects of karst on human activities are illustrated by Photos 1.27–1.29.

1.4 Suffosion

Suffosion is the leaching and removal of fine mineral particles by underground water flows.

The economic effects of suffosion are more frequently related to the formation of subsurface voids. Suffosion has effects on the following engineering *structures*: (1) industrial and civil engineering structures; (2) motor roads and railroads; (3) bridges; (4) mining enterprises, and (5) hydraulic facilities. In addition, suffosion is an important factor in the initiation and development of a number of unfavourable natural processes (Govorushko 2009b).

The effects of suffosion on *industrial and civil structures* become apparent as buildings located over underground voids show deformations. Examples include the following: the demolition of more than 50 houses in a suburb of Brasilia (Brazil); deformations of more than 100 houses in the 1970s in Erevan, Armenia; and destruction of a freight yard in 1980 in Rossville (state of Georgia, United States). In this last case, the losses reached US$1.4 million (Kurbatova et al. 1997).

The influences of suffosion on *motor roads and railroads* are shown by deformations due to suffosion craters. Several cases of road accidents caused by suffosion, with body counts of up to 10–12, are known (Myagkov 1995). The impact on *bridges* shows itself as instability of their abutments.

The influences of suffosion on the *mineral resource industry* are related to abundant inflow of underground waters to the mine openings – underground mines, open pits, etc. – through suffosion channels. Suffosion also creates problems for oil extraction in the Surgut field in Russia (Exogenous geological dangers 2002).

The effects on *hydraulic facilities* are related to water leakage through suffosion hollows from irrigation canals; they fill with products of subsurface erosion. The problem of suffosion is quite pressing for the irrigation systems of Ciscaucasia and Trans-Volga (Russia); most reservoirs of the Volga, Kama, and Angara River cascades; as well as the Tsimlyansky, Novosibirsk, and Krasnoyarsk Reservoirs (Russia).

Suffosion contributes considerably to the origin and development of many *natural processes*. Among them are landslides, rockfalls, subsidences, rock streams, and so on. Landslides that are initiated by suffosion niches undercutting slopes are quite typical. Such a landslide

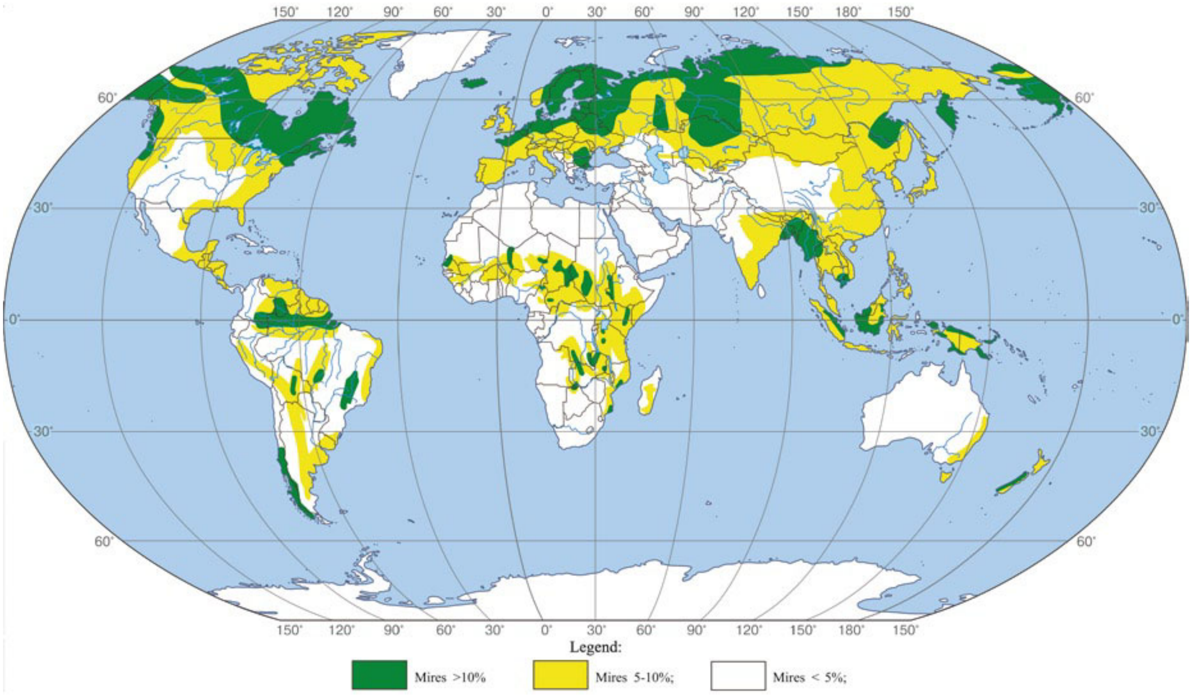

Fig. 1.7 Global distribution of peatlands (http://www.peatland.gov.uk/images/formation/globdist.gif; Reproduced with permission of Environment and Heritage Service, Beltfast, UK)

was the cause of the destruction in 1983 of a five-storey apartment building in the city of Kurgan, Russia; as a result, 14 people were killed (Khomenko 2006).

As for *economic losses* resulting from suffosion, the only known estimate is for Russia and amounts to 200 million British pounds, that is, about US$356.8 million a year (Khomenko 2006). We believe this estimate is excessive.

1.5 Swamping

At first glance, the assignment of swamping to the category of *geological* processes seems to be illogical. Nevertheless, it makes some sense. When swamp areas are being developed, engineering-geological problems affecting the construction of structures on the peat and peaty rocks inevitably arise. The *geological* role of swamps is also significant. In this respect, practically all engineering geology textbooks include sections devoted to swamping.

Swamps occupy 2.1% of the Earth's land area. Besides swamps, *swamplands* are also recognized. They include territories where the peat layer thickness is such that the roots of most plants that grow there reach the underlying mineral ground. The countries where swamps and swamping territories are *widespread* include Russia, Canada, Finland, Estonia, Belarus, Brazil, Congo (Kinshasa), Paraguay, Indonesia, and India. The total volume of peat on Earth is estimated at 12,000 km³ (Ecological Encyclopaedia 1999).

The negative consequences of land swamping are caused by the following *factors* (Exogenous geological dangers 2002): (1) destruction of pavements and resulting impassability of roads; (2) reduction in the bearing resistance of ground, affecting the stability of power transmission towers, pipelines, and so on; (3) drinking water quality deterioration due to microbiological pollution and other biochemical processes; and (4) reduction in the quality of agricultural lands and forests.

The distinctive feature of swamps is the accumulation of *peat*. Peat is a biogenic rock consisting of aggregations of plant residues subjected to incomplete decomposition due to reduced access to oxygen. The global distribution of peatlands is shown in Fig. 1.7.

The *major properties* of peat and peaty rocks that determine their building qualities are the following

Photo. 1.30 Swamping, besides other effects, leads to peat formation. Peat is capable of generating heat; therefore, it is widely used for heat energy. The photo shows Falkland Islanders shovelling peat (ca 1950) (Photo credit: http://en.wikipedia.org/wiki/File:Showel-Falklands.jpg, unknown author)

(Lomtadze 1977): (1) high natural humidity; (2) low density, (3) high water capacity; and (4) considerable and irregular deformability (compressibility). These features determine their low suitability for construction. However, in many cases, it is impossible to do without the development of swamping territories. The *first large-scale experience* of such construction was with the Liverpool–Manchester Railway (UK), which opened for traffic in 1830. The railway crossed the large Chat Moss swamp, which had thick peat deposits. The project manager, George Stephenson, successfully submerged a large quantity of deadwood within the peat mass until it was compressed to such an extent that an artificial foundation was formed (Anderson and Trigg 1981).

Nowadays, construction on boggy deposits occurs mostly in the development of natural gas and oil fields in the northlands. For example, the Ust-Balyk–Omsk oil pipeline in Russia passes through swamps and swamping lands over a length of 125 km (Sergeev 1978). Underestimating the properties of boggy deposits can result in drastic consequences in construction projects. In Arkhangelsk, Russia, peaty bogs occupy 75% of the city's territory (Kotlov 1978). In many cases, the construction of wooden buildings on peat has resulted in settlement of 3–4 m (at an unevenness of 0.3–1.3 m), which has caused their complete destruction (Lomtadze 1977).

Swamping also has *positive consequences* for some kinds of human activity: (1) mineral resource industry; (2) thermal power engineering, (3) chemical industry; (4) crop production; (5) livestock farming; (6) industrial and civil engineering; and (7) medical services.

A positive influence on the *mineral resources industry* is related to the formation of a number of minerals (*limestone, bog iron ores*, mineral pigment – *vivianite*). However, *peat,* having estimated world reserves of more than 500 billion tons, is the most valuable mineral. The following countries possess the greatest reserves of peat (billion tons; peat humidity is 40%): (1) Russia, 235; (2) Indonesia, 78.5; (3) the United States, 36.3; (4) Finland, 35; (5) Canada, 35; (6) China, 27; (7) Sweden, 11.2; (8) Germany, 7.3; (9) Ireland, 5.8; and (10) Great Britain, 5.7 (Kosov 2000).

The effects of swamping on *thermal power engineering* are related to the peat caloric efficiency. Its calorific value at a humidity of 40% is 2,800–3,000 kcal/kg (Geographical encyclopaedic dictionary 1988). In a number of electric power stations in Belarus, northern regions of European Russia, and other places, peat is used as a power resource.

The effects of swamping on the *chemical industry* are related to the production of a number of compounds that are obtained from peat (peat wax, colouring agents, bitumen, tannins, acetic acid, humic acid, oxalic acid, surfactant species, ammonia, tar, and others).

The effects of swamping on *crop production* are based on the use of peat as a fertilizer, enriching the soil with humus and improving its physical–mechanical properties, structure, and water–air regime. Peat is successfully used as a litter in *livestock farming,* which makes it possible to improve hygienic conditions of livestock handling and to increase the amount of high-efficiency composts (Kosov 2000).

Peat is widely used in the *construction industry* for the following: (1) production of heat- and sound-insulating materials; (2) production of building materials; and (3) production of cohesive materials.

Many therapeutic–hygienic agents based on peat extracts have been developed for applications in *medicine* for treating different chronic dermatoses (psoriasis, eczema, neurodermatitis, seborrhoea, tinea, and others).

The effects of swamping on human activities are illustrated by Photo 1.30.

1.6 Floating Earth and Quicksands

Quite often, human activities are complicated by *floating earth* – moisture-laden loose sediments that are capable of spreading and sloughing under the pressure of the overlying stratum and as a result of other mechanical effects. For the most part, the phenomenon of sloughing is characteristic of very fine-grained, pulverescent, water-bearing sands and, more rarely, loamy sands and clay loams that come to an unsteady state in stripping by borrow pits and mine workings. Sloughing can occur both slowly, with thick layers, and quickly and catastrophically, in the form of a break.

Floating earths are widely *distributed* in Germany, Belgium, the Netherlands, Great Britain, the United States, Russia, Uzbekistan, and other countries.

Catastrophically quick motions of floating earths, which hamper construction and mining operations considerably, are the most dangerous. For example, if a rock flow begins at the bottom of a slope, then the overlying mass loses its support, and its stability is disturbed. When floating earths are stripped at an underground opening, they fill it, while the rock above it begins to move. Sometimes, a zone of influence of the underground opening reaches the Earth surface, resulting in cave-ins.

In 1974, an underground opening was created in floating earths at a depth of 80 m in the course of subway construction in Leningrad, Russia. In order to prevent sloughing, the sands were preliminarily frozen. However, within one sector, the running sands proved notto be frozen, and a rush formed. A general failure of the rock mass stability took place, thousands of cubic metres of the floating earth quickly filled a portion of the tunnel, and on the Earth's surface, a subsidence trough formed (Lomtadze 1977). A rush of floating earth to the surface is also possible while the subway is in service. Such events have been noted in the case of increases in traffic volume and when trains speed up within sectors where the running formations occurred at some depth (Druzhinin 1987).

Events are known when floating earths caused *human losses*. In the fall of 1932, catastrophic sloughing happened in one of the brown coal pits in Germany. The coal pit had dimensions of 2 by 1 km and a depth of 45 m. The stream of liquid ground transported more than 1.5 million tons of sand. The lower bench was covered with a layer of loose rock, 19 m thick; several people were killed, and the excavator and other working equipment were buried (Larionov 1974).

Quicksands are formations related to floating earths – unfixed, very fine-grained, and oversaturated sands. They occur on many sea and river shores as well as at the mouths of rivers. A passage containing a description of quicksands in England is included in the novel *The Moonstone* by Wilkie Collins. An event is known when, in the spring of 1945, in Germany, an American truck pulled off the road into the bushes, taking cover from German aircraft. A few minutes later, when the aircraft had flown away, the driver could not open the cab doors because the truck was sinking into quicksands. The driver managed to save himself by getting out through the cab top and grasping a nearby bush, while the truck was sucked down. The loss of an American student in quicksands in 1982 is also known (Mezentsev 1988).

So far, the *mechanism of action* of quicksands has not been elucidated. In one opinion, the cause is the

Photo 1.31 Swelling is generated by increases in the volume of clay minerals during water penetration into dehydrated ground. Non-uniform elevation of surfaces after dampening deforms structures. The photo shows a crack in the wall of a building induced by swelling in the state of Colorado (United States) (Photo credit: U.S. Geological Survey, January 1971)

regular spherical shape of grains of sand, while in another view, it is the high slipperiness of the grains.

1.7 Swelling and Shrinkage

Swelling is a rise of the surface of wetted soils and grounds as a result of their expansion in the course of freezing and bulking. *Shrinkage* is the ability of rock to decrease in volume with reductions in moisture. Swelling and shrinkage are inextricably connected processes: Swelling of rocks is a prerequisite for shrinkage. Cryogenic swelling was considered in Sect. 1.2.1.

An *increase in volume* in the course of swelling is characteristic of clays and rocks containing clay particles in amounts of 4% and more; they are called shrink-swell clays. This kind of swelling causes difficulties for construction in such countries as the United States (primarily in Texas, North Dakota, South Dakota, Colorado, and Montana), India, Pakistan, Great Britain, the Federal Republic of Germany, the Republic of South Africa, China, the Czech Republic, Argentina, Brazil, Moldavia, Ukraine (south-western regions, the Crimea), Transcaucasia countries, Uzbekistan (delta of the Amu Darya River), Tajikistan (the lower reaches of the Murgab River), and others. In Russia, the most dangerous territories occupy an area of 240,000 km^2, which corresponds to 1.4% of the total area of the country (Exogenous geological dangers 2002).

The basic *groups of factors* influencing the swelling/shrinkage capacity of clay rocks are the following (Exogenous geological hazards 2002): (1) granulometric and mineral composition; (2) texture and condition of clay rocks; and (3) physico-chemical factors (composition and concentration of salts in solution, temperature, permittivity of fluid, etc.).

Swelling occurs when water penetrates into dehydrated ground. It is initiated by the following *conditions* (Legget 1976): (1) infiltration during rains; (2) variations of the levels of subsoil water; and (3) reduction of evaporation in cases where the ground is covered (e.g. roadways, house footings). When clay rocks are moistened, internal stress (swelling pressure) arises inside a mass, whereupon the rock mass increases in volume and there is a rise of its surface at rates of up to 2 mm/day. Clean montmorillonite clays saturated with cation Na^+ can expand by 450% when they are moistened (Exogenous geological dangers 2002). According to data obtained by A.K. Larionov (1974), when the water content increases by 10–15%, swelling forces reach 40–50 ton/m² of surface.

The swelling and shrinkage of clay rocks affect the following human activities and *structures*: (1) industrial and civil engineering; (2) motor roads and railroads; (3) pipelines; and (4) underground facilities.

The effects on *industrial* and *civil engineering* consist of different deformations. They arise when a load transmitted to the ground by the structure base exceeds the swelling pressure. Cracks at door and window openings and in walls appear, and building segments become skewed to the point of demolition of the structure. Mass deformations of three- and four-storey apartment buildings in one of the districts of Volgograd are widely known. Due to negligence in allowing drainage of rainwater from roofs, there was a humidification of montmorillonite clays with subsequent swelling. With thickness of the wetted layer of 20–30 cm, swelling resulted in a rise of the foundation segments of 3–5 cm, which caused numerous deformations (Larionov 1974).

The effects on *motor roads and railroads* involve complications in their operation due to deformations of embankments and damage to the road covering. The influences on *pipelines* and *underground facilities* (communication cables, electric cables, etc.) cause them to break. Economic losses related to swelling and shrinkage of clay rocks are considerable. For example, they reach US$2.3 billion a year in the United States, about US$100 million per year in Great Britain, and ten million South African rand (US$1.3 million) in the Republic of South Africa (Exogenous geological dangers 2002).

The effects of swelling on human activities are illustrated by Photo 1.31.

1.8 Land Subsidence

Land subsidence is a reduction in porosity and compaction of porous soils due to their water soaking. The phenomena of subsidence are characteristic of loess, which includes the loess proper of aeolian origin and loess-like deposits of different genesis (glacial, alluvial, deluvial, proluvial, etc.). The loess occurs over an area of 3.8 million square kilometres (Ananyev 2004), while the loess-like deposits occur on territories of 9.2 million square kilometres (Abelev and Abelev 1979). Thus, the loess rocks cover about 10% of the world's land surface (Fig. 1.8).

The loess mass with the *greatest thickness* in the world is present on the Loess Plateau in China, where, in the middle part of the Hwang Ho River basin, it ranges from 100 to 250 m (Natural-anthropogenic processes and environmental risk 2004). The thickness of loess reaches a record value (400 m) near the city of Lanzhou (Gansu Province capital) (Exogenous geological hazards 2002).

The most important diagnostic characteristic of loess rocks is their *macroporosity,* which is indicated by the presence of tubules and canaliculi of irregular shape (from 0.1 to 3 mm in diameter); these small structures run in the rock mainly in vertical. From 3 to 25 macropores are present within 1 cm² of the rock. The volume weights of macroporous loess rocks range from 1.28 to 2.11 g/cm³. Loess grounds sag if they have a volume weight less than 1.55 g/cm³ and if they occur above the groundwater line (Abelev and Abelev 1979).

Dried loess rocks have sufficient strength; however, their contact with water leads to swelling of the macropores and abrupt postcompaction of the rock (due to both the deposits' own weight and the action of installation loads). Land subsidence has been known to decrease the thickness of rocks by 10% (Legget 1976).

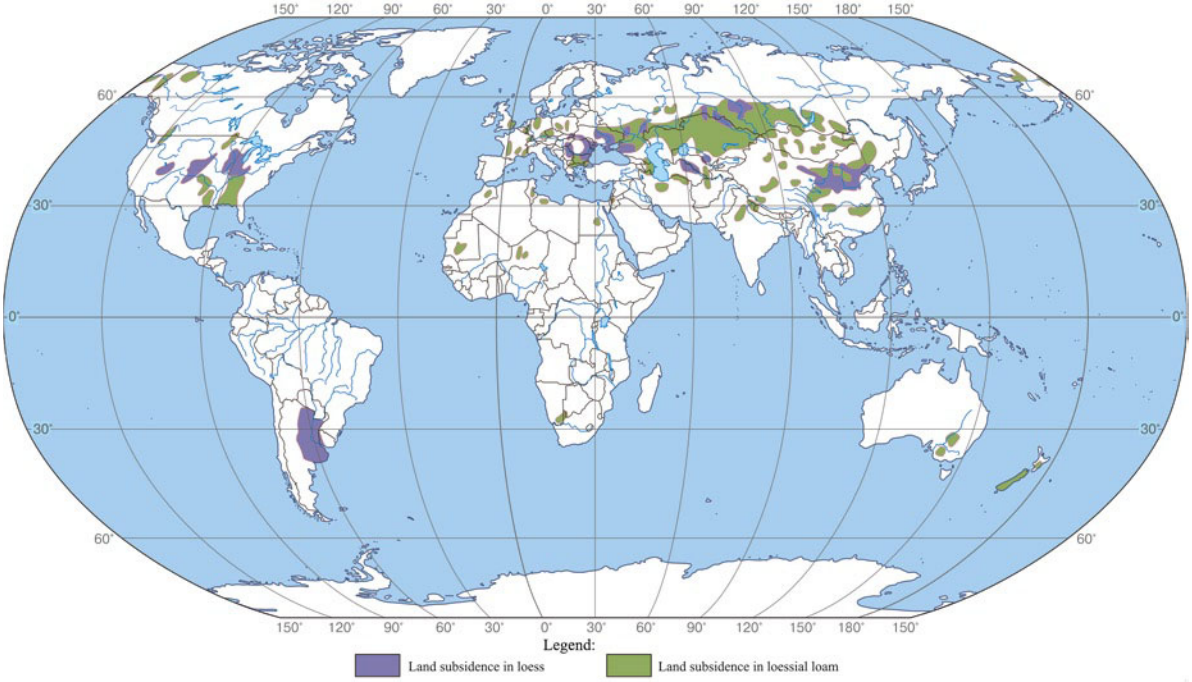

Fig. 1.8 Global distribution of land subsidence (Loess cover the Earth 2001. Reproduced with permission of Moscow State University, Russia)

Photo 1.32 Loess, when dampened with water, diminishes in volume. This feature accounts for ground subsidence. Non-uniform sinking produces cracks in walls, distorts doorways and window openings, and tilts or even completely destroys buildings. The photo shows the tilt of a window opening in a dwelling in south-eastern England (Photo credit: Ilan Kelman; http://www.ilankelman.org)

Photo 1.33 The Tower of Pisa stands on limous and clayey ground. Its 'fall' is caused by nonuniformity of subsidence of underlying ground. Its south side subsided 3 m deep, and the north, 1 m deep. Non-uniform subsidence has been occurring for eight centuries, and today, the tower's plumb-line deviation is 4.9 m. Nowadays, toppling of the tower is stopped thanks to a set of preventive measures (Photo credit: http://en.wikipedia.org/wiki/File:Leaning_tower_of_pisa_2.jpg, unknown author)

Strain intensity determines the following *factors* (Druzhinin 1987): (1) water saturation extent; (2) deposit porosity; (3) pressure level; (4) total dissolved salts; (5) steeping duration; and (6) thickness of the subsiding rocks.

More often, land subsidence has effects on the following kinds of human activity and *structures*: (1) residential construction; (2) industrial structures; (3) underground facilities; and (4) irrigation canals.

Residential and *industrial structures* situated on loess grounds can experience land subsidence as a result of both ingress of moisture from above and inundation of the layers of loess from below. Because subsidence rates vary from one place to another, subsidence results in the initiation of cracks in buildings, inclination of buildings, and sometimes in their complete demolition. An example of the complete demolition of a building that occurred in British Columbia (Canada) is given by R.F. Legget (1976).

Impacts on *industrial objects*, in addition to deformations and destruction of buildings, are evident in the breakdown of processes and problems related to equipment operation. For example, A.K. Larionov (1974) describes in his book the problems that arose in the course of construction on loess grounds of two blast furnaces and a thermal power plant. Quite often, considerable differential subsidence results in breakage of *underground facilities* (especially water supply systems).

The effects on *irrigation canals* become apparent in channel bed deformation, which results in operating trouble. Numerous examples of failure of irrigation canals in Ciscaucasia, central Asia, and China are presented in the work by A.K. Larionov (1974).

Land subsidence causes great *economic losses,* which are especially high in urban areas. In Russia, this process is characteristic of 563 cities, and annual losses amount to US$500–700 million. Extreme cases of subsidence are characteristic of the city of Volgodonsk (Rostov oblast, Russia), where 733 residential and public buildings (84% of the total number) are at risk. Total financial losses from loess subsidence in this city reached US$400 million by 1996 (Exogenous geological hazards 2002).

The effects of land subsidence on engineering structures are illustrated by Photos 1.32 and 1.33.

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Internet Resource

http://tsun.sscc.ru/tsulab/20041226fat_r.htm

2 Geomorphologic Processes

Abstract

Geomorphology is the science that studies the Earth's surface relief. Exogenous geomorphologic processes occur on the Earth's surface and in the upper crust. These surface horizons become susceptible to displacement through weathering – chemical changes and destruction of rock due to the actions of the atmosphere, water, and organisms. Geomorphologic processes are subdivided into slope (removal of material from slopes under the action of gravity), fluvial (connected with the activity of temporary and perennial streams), aeolian (relief-forming processes caused by wind action), coastal (relief-forming processes within the littoral zone caused by the action of waves and currents), and others.

Keywords

Geomorphology • Geomorphologic processes • Rates • Mechanisms • Human activity • Economic loss • Mortality

2.1 Rockfalls

A *rockfall* is a catastrophic fall of great rock masses on steep and scarp slopes. Rockfalls are widespread in countries such as Switzerland, Austria, Romania, Norway, India, Nepal, Colombia, Ecuador, Peru, Chile, the United States, Canada, countries in central Asia and Transcaucasia, and others.

A basic *cause* of rockfalls is instability of rock bodies on slopes. They can be caused by constant gravity and cycling water-pressure-induced forces in cracks of rocks; seismic stresses caused by earthquakes; and vibrations owing to traffic flow, blasting operations, and other sources. For rockfalls to occur, it is essential that exposed hard formations be driven by *weathering* processes to such a state that their internal shear forces are not able to balance the action of external forces.

Rock fracturing is a factor *contributing* to the development of rockfalls. Of fundamental importance is the direction of the dip of the crack faces. For rock failure, joints where faces are inclined to the slope base are favourable. If the joints point deep into the slope, there is a seizure of rock slabs that is not favourable to the development of a rockfall. The bigger distance between cracks, the higher the potential danger due to the great destructive force of large falling blocks. The first autumn frosts, avalanches, spring thaws, showers, hurricanes, earthquakes, activities of ground and surface waters, incorrect execution of mining operations, and other processes are possible immediate causes of rockfalls (Druzhinin 1987).

The most typical feature of rockfalls is their comparative suddenness. *The duration* of a rockfall is only several minutes, but processes that lead up to them can

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Photo 2.1 Rockfalls impact human activities when the rock fragments fall down, objects are coated with sediment, air waves are produced, etc. The rockfall of 11 July 1996 in Yosemite National Park, California (United States), killed 1 and injured 14. The airwave blew down approximately 2,000 trees (Photo credit: Edwin Harp, U.S. Geological Survey)

last hundreds of thousands of years. The speed at which the fragments fall can reach 200 km/h (Zaruba and Mencl 1979) and even up to 324 km/h according to data obtained by A.S. Kurbatova et al. (1997).

Rockfalls cause problems for the following *kinds of human activity and structures*: (1) residential construction, (2) transport (motor, rail, pipeline), (3) transmission facilities, (4) agriculture, and (5) hydropower engineering.

In the history of mankind, quite a number of catastrophes are known when rockfalls resulted in the destruction of *settlements* located at the foot of a mountain. They include a rockslide off Rossberg in the Alps on 2 September 1806. A total of 953 people, 395 head of livestock, 183 households, 126 occupied houses, 85 b, and other buildings were wiped out (Larionov 1974). When a rockfall occurred in 1881 near Elm (Switzerland) as a result of a steep slope failure by several borrow pits, the event destroyed 90 ha of arable land and 83 buildings and killed 115 people (Zaruba and Mencl 1979).

A rockfall that occurred on 29 April 1903, in the city of Frank (Alberta, Canada), is widely known. It killed 70 people, buried 1.6 km of railway lines, and caused record damage to the city. After the rockfall, the city was moved 2 km farther north (Smith 1992).

The effects of rockfalls on transport include blockage of *highways* and *railways* by the deposit layer, damage to roadbeds, and destruction of engineering structures, which result in traffic disturbances. For example, 428 rockfall events were recorded along the Transcaucasian Railway during a period of 5 years (1955–1959), whereby 3.5 million cubic metres of rock was needed to be taken away (Alekseev 1988). Sometimes, *wreckage of transport vehicles* due to immediate impact of rockfalls has been noted. In March 1981, part of a passenger train was buried at a distance of 182 km from Belgrade as a result of a rockfall. Sixteen people were killed, and 35 were injured (Kovalevsky 1986). Quite often, rockfalls damage *pipelines* and *transmission facilities*.

The impact of rockfalls on *agriculture* consists of destruction of arable and grazing lands as a result of their being buried underneath rock fragments. The influence on *hydropower engineering* is in decreasing the capacity of reservoirs, which results in reductions in electricity production.

One indirect influence of rockfalls on human activity is related to the falling of blocks into water bodies, which results in the formation of *waves*. For example, disastrous effects are sometimes characteristic of rockfalls on the steep slopes of the Norwegian fiords, leading to the generation of huge waves that burst upon the shore (Zaruba and Mencl 1979). As a result of a rockfall in the Alps in 1906, Lake Lauerz was partially buried. Moreover, the 20-metre wave washed down dozens of houses (Larionov 1974).

The *mortality* from rockfalls reaches 20–30 people a year, while *economic loss* reaches US$50–60 million (Govorushko 2007a). The effects of rockfalls on human activity are illustrated by Photos 2.1–2.4.

2.2 Screes

Screes are accumulations of non-graded angular fragments of rocks produced as a result of rolling or sliding of fragments of rocks that have been destroyed by weathering on steep slopes. Like rockfalls, screes are,

Photo 2.2 Roads are very often blocked by the layer of sediment produced by rockfalls. The photo shows a slight rockfall that cut off a road to the resort city of Palm Springs in south-western California (United States). Rockfalls are constantly hampering the use of this road and pose a grave threat to traffic (Photo credit: National Geophysical Data Center, United States, July 1986)

Photo 2.3 The impacts of rockfalls on motor transportation in mountain areas are widespread, yet direct impact of stone fragments on vehicles is rare. This car was crushed by a rockfall on Lefkada Island, Greece (Photo credit: Geobrugg AG – Protection Systems, Romanshorn, Switzerland, 2005)

first of all, characteristic of young mountain systems; therefore, their distributions are practically identical.

A scree slope can be subdivided into three *components* (Engineering geology reference book 1981): (1) feed area (detachment of fragments), (2) transit area, and (3) accumulation area. The rambling effect varies with space and time. The *intensity peak* is observed in spring, at the time of thawing, while in winter, when

Photo 2.4 Mitigation measures against rockfalls are usually costly. The most exposed sites are typically protected by special flexible anti-rockfall barriers. Elements of a particular protective system are chosen based upon the presumable power of a maximal strike. The photo shows anti-rockfall flexible barriers in Wolfsnack, Germany (Photo credit: Geobrugg AG – Protection Systems, Romanshorn, Switzerland, summer 2004)

Photo 2.5 Similar to rockfalls, screes are characteristic, in the first place, of young mountain systems. Screes in the Rocky Mountains (Canada) are shown (Photo credit: U.S. National Oceanic and Atmospheric Administration, 1989)

Photo 2.6 As they fall, coarse rock fragments travel faster and farther than small ones; therefore, they predominate at the foot of a slope. A scree in eastern Switzerland is shown. The presence of vegetation (at the lower part of the slope) suggests a gradual slope stabilization (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 1 September 2006)

rocks are frozen, the process intensity is ten times lower. In addition to seasonal variations, there are year-to-year *intensity oscillations*. A scree is formed where a slope flattens or near the foot of a slope. In the event that it is undermined or undercut with the formation of a hollow, a failure of a part of or the entire accumulated mass so that it falls into the hollow is possible. Displacement of fragments in the form of separate blocks is called a (rock) *slump*. They appear when screes are moistened sharply due to showers and when friction and adhesion between fragments lessen, as well as in the course of earthquakes (Druzhinin 1987).

The *characteristics of screes* depend on many factors (petrographic composition, shapes and sizes of fragments, slope height, inclination, etc.). When sloughing occurs, large masses of rock debris move faster than small masses; therefore, the composition of the accumulations coarsens down the slope. The *scree cone* grows until denudation completely flattens the rock outcrops feeding the scree. When the accumulations reach a slope with an inclination less than the natural slope angle, a scree turns into a *rock stream*.

The *sizes of screes* vary widely. Sometimes, a scree is a small heap of fragments having an area of some square metres, and at other times, huge accumulations with areas of up to 1 km^2 are formed. Fluctuations in the thicknesses of screes also occur: from tens of centimetres to 30–50 m.

Screes influence, most importantly, the following *kinds of human activity and structures*: (1) transport (motor, rail, pipeline), (2) transmission facilities, (3) hydropower engineering, and (4) crop production.

The effects on *transport* include complication of the construction and operation of *highways* and

Photo 2.7 Screes do not infrequently aggravate the construction and maintenance of diverse linear objects, for example, auto roads and railroads, pipelines, and power lines. Their impacts are exerted both through dynamic impact of fragmental products and through blockage of a road with a layer of sediment. The photo shows a scree that blocked a road near Randa, Canton du Valais, Switzerland (Photo credit: Andreas Goetz, PLANAT, Switzerland, 23 October 2002)

railways (damage to roadbeds, blockage with debris) and the destruction of *pipelines.* The effects on *transmission facilities* are related to damage to towers, resulting in power interruptions. The effects on *hydropower engineering* result from reduction in the capacity of reservoirs when they are filled with rock fragments. The damage to *crop production* is caused by reduction in cultivable land areas.

The influences of screes on human activity are illustrated by Photos 2.5–2.7.

2.3 Avalanches

An *avalanche* is a fast descent of snow cover along slopes under the influence of gravity. Snow avalanches take place on all continents and in all climatic zones. *Avalanche trigger zones* occupy about 6% of the terrestrial parts of the world. Their distribution in different regions of the world is illustrated in Fig. 2.1.

For avalanche *formation*, three *conditions* are needed (Atlas of the world snow-ice resources 1997, vol II, Book 1): (1) at least an episode exceeding the average thickness of a snow mass of 30–40 cm, (2) a slope inclination more than 15°, and (3) a relative elevation of a slope more than 40–50 m. The part of the slope where the snow avalanche is born, moves, and stops is called the *avalanche catchment*. Within its boundaries, three zones have been identified: (1) origin, (2) transit, and (3) deposition.

Within the snow cover on a slope, *two differently directed forces* act: cohesion and gravity. *Cohesion* tends to hold snow cover on a slope, while *gravity* moves it downward. When the gravity force exceeds the cohesion force, a snow avalanche is formed. An avalanche can be formed for the following reasons: (1) cohesion force decreases, (2) gravity force increases, and (3) a combination of the above (Geocryological dangers 2000).

The *periodicity* of snow avalanches changes markedly depending on local conditions (from one time per 300–500 years to 10–15 times a year at the same site). Their volumes vary from several tens to several million cubic metres. Avalanches of up to 5–6 million cubic metres in volume are known (Natural-anthropogenic processes and ecological risk 2004).

For the *formation of avalanches*, the following *meteorological factors* are of particular importance

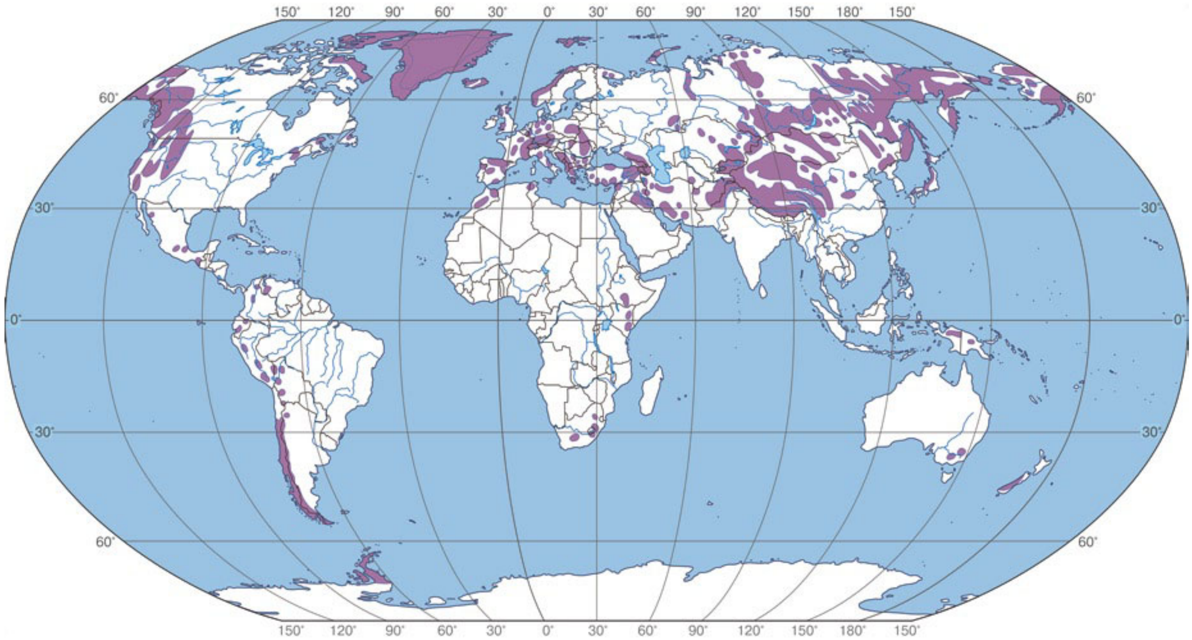

Fig. 2.1 Avalanche-prone areas of the world (Atlas of the world snow-ice resources 1997, vol 2, Book 1. Reproduced with permission of Geography of the Russian Academy of the Sciences)

(Geocryological dangers 2000): (1) snowfalls, (2) snowstorms, (3) prolonged periods of cold temperatures, (4) thaws, (5) snow melting, and (6) rainfall on the snow surface. Besides these, one can also note the effects of *earthquakes*, *vegetation cover*, and *anthropogenic factors.* More than 80% of avalanches are due to snowfalls.

Avalanche *velocities* are 10–60 m/s (Losev et al. 1991); however, in cases of the greatest avalanches on slopes of more than 35°, they may reach 125 m/s, that is, 450 km/h (Dynamics of snow and ice masses 1985). The *pressures* of a snow avalanche on a fixed obstacle are 6–40 ton/m^2 (Stoiko and Tretyak 1983). In Japan, this factor once reached 300 ton/m^2 (Stukov 2001).

The influences of snow avalanches on *human activities* have been noted throughout history. Hannibal lost about 18,000 men in avalanches as he crossed the Alps to battle the Roman army. He also lost 2,000 horses and many elephants (Stoiko and Tretyak 1983).

At the Austrian–Italian line during World War I, 60,000 soldiers were killed by avalanches. On 16 December 1916 alone, a series of avalanches took the lives of over 6,000 soldiers; this day was called 'Black Thursday' (Kotlyakov 1994).

The *deaths of people* caught in snow avalanches are generally caused by the *following* (Snow 1986): (1) asphyxia due to lungs filling with powder snow, pressure on the chest, or lack of oxygen, (2) destruction of buildings, falls, and impacts on rocks and trees, (3) shock (fright, fear), and (4) hypothermia. Chances of rescue depend on how deep and how long one is buried.

Snow avalanches affect structures and the *economy* through the following means (Govorushko 2008a): (1) impact of the snow mass, (2) burial with snow, and (3) impact of the air wave. The destructive effect of the *impact* of the snow mass depends, in many respects, on snow density and avalanche velocity. Most often, buildings, bridges, pipelines, transmission facilities, and mining enterprises are destroyed, and trains and transport vehicles are damaged along the way. In 1974, an avalanche destroyed a restaurant in British Columbia (Canada) and killed seven people. In 1971, avalanches demolished seven houses, killed four people, and injured four men in Washington state (United States) (Snow 1986).

A series of 649 avalanches killed over 265 people in the winter of 1950–1951 in the Swiss–Austrian Alps. Austria lost thousands of acres of forest, several small villages, and more than 100 lives. Switzerland lost 900 buildings and 92 lives (Kotlyakov 1994).

Photo 2.8 The impact of a snow mass is characteristic of any avalanche. Its destructive effect mainly depends on the snow density and the avalanche velocity (The photo shows movement of an avalanche. Photo credit: http://simple.wikipedia.org/wiki/Avalanche)

Photo 2.9 Avalanches typically fill up everything they meet on their way. They cover people, stand-alone buildings, vehicles, and communication lines. The photo shows the outcome of the avalanche of 3 January 2000 near Cordova, Alaska (United States) (Photo credit: D. Saville, Federal Emergency Management Agency (United States))

Photo 2.10 Auto roads are among the objects that suffer most from avalanches. Traffic is usually blocked by the snow mass that coats the roadway, as you can see in this photo. However, sometimes the very impact of the snow mass on a road embankment is critically important (Photo credit: U.S. National Oceanic and Atmospheric Administration, 15 February 2002)

Burial with snow is a pervasive phenomenon. Quite often, the snow sweeps up people, single buildings, and transport vehicles, but the most characteristic consequence of this process is disruption of transportation. Avalanches stop motor and rail traffic and interrupt power supplies and communications. The proximate damages are quite often accompanied by heavy consequential damages related to travel delays and service outages.

As an example of burial with snow, one can give the great avalanche catastrophe that occurred on the night of 1 March 1910 in the Cascade Range (Washington state, United States). Three trains (passenger, mail, and work) were swept up by an avalanche. The snow avalanche had a length of 1 km, a width of 500 m, and a thickness of 6 m; it killed 120 people (Kukal 1985).

The air-wave effect is characteristic of dry-snow avalanches. It causes destruction beyond the area of the avalanche snow deposit. For example, in 1983, the first floor of a wooden house was blown off by the air wave during a great dry avalanche in Japan. It flew approximately 800 m and was broken against rocks, together with the people in it (Alekseev 1988). On 29 February 1908 in the Swiss borough of Goppenstein, a small avalanche did not reach a hotel; however, the hotel roof was carried to the opposite side of the valley, and 12 men who were sitting at a table facing the avalanche were suffocated by the sharp air pressure drop. Several tourists sitting with their backs to the avalanche did survive (Mezentsev 1988). And again in Switzerland, an air wave moved a railway car 80 m and threw a 120-ton electric locomotive into a terminal (Kotlyakov 1994).

Globally, the average annual *mortality* from avalanches can be estimated at 200 people, while yearly direct *economic losses* are at US$300–400 million (Govorushko 2008a). The effects of avalanches on human activities are illustrated by Photos 2.8–2.13.

Photo 2.11 There are many ways to protect objects and people from avalanches. One of them is erecting snow-stabilizing barriers. The increase in roughness of the slope surface helps stabilize the snow blanket and prevents avalanches from passing. The photo shows anti-avalanche backstops in western Switzerland (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 28 August 2006)

Photo 2.12 Another method of mitigating the effects of avalanches is damping structures that protect engineering projects against avalanches in progress. At the places of origin of small avalanches, steel nets are used. A flexible mesh barrier used against snow avalanches in Austria is shown (Photo credit: Geobrugg AG–Protection Systems, Romanshorn, Switzerland, February 2006)

Photo 2.13 A church was first built here in the middle of the fourteenth century, and after that, it was damaged or destroyed by avalanches many times – once every 30 years on average. That trend was stopped in the middle of the sixteenth century when a still-existing avalanche breaker building was erected. Since then, this church in Davos, Switzerland, hasn't been damaged. The building of similar construction below the church was built in 2005 (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 31 August 2006)

2.4 Landslides

A *landslide* is a displacement of masses of rocks forming a slope through a sliding motion, generally without loss of contact between the moving rocks and the stationary rocks. The geographical distribution of landslides is illustrated in Fig. 2.2.

The *major cause* of landslide formation is a disturbance of the equilibrium of the rocks or reduction in their strength, which in turn can be determined by *two types* of processes: (1) natural processes (ground overwetting, seismic impacts, slope over-steepening, and undermining of a slope by sea and river waters), and (2) anthropogenic (undercutting of slopes and increasing loads on them during construction; ploughing up of territory, allowing precipitation to permeate the soil; and vegetation destruction, weakening root systems that had been binding the soil, etc.).

Creep rates differ by several orders of magnitude. Some landslide blocks move at rates of several centimetres a year with breakdowns that occur several decades apart. The fastest landslides move at rates up to 120–320 km/h.

Impacts of landslides on structures are possible in two *situations*: (1) a facility is located near the landslide block, or (2) a structure is located below the landslide block. When a landslide block is moving, the stability of a rock mass serving as a base for a structure can be disturbed, and this structure can begin to move with the base. By virtue of a slide's nonuniformity, this displacement can result in settling of structures, distortions in construction, equipment dysfunction, and, quite often, destruction of structures. If a structure is situated below a landslide block, the destructive consequences mainly result from dynamic impact of the moving mass.

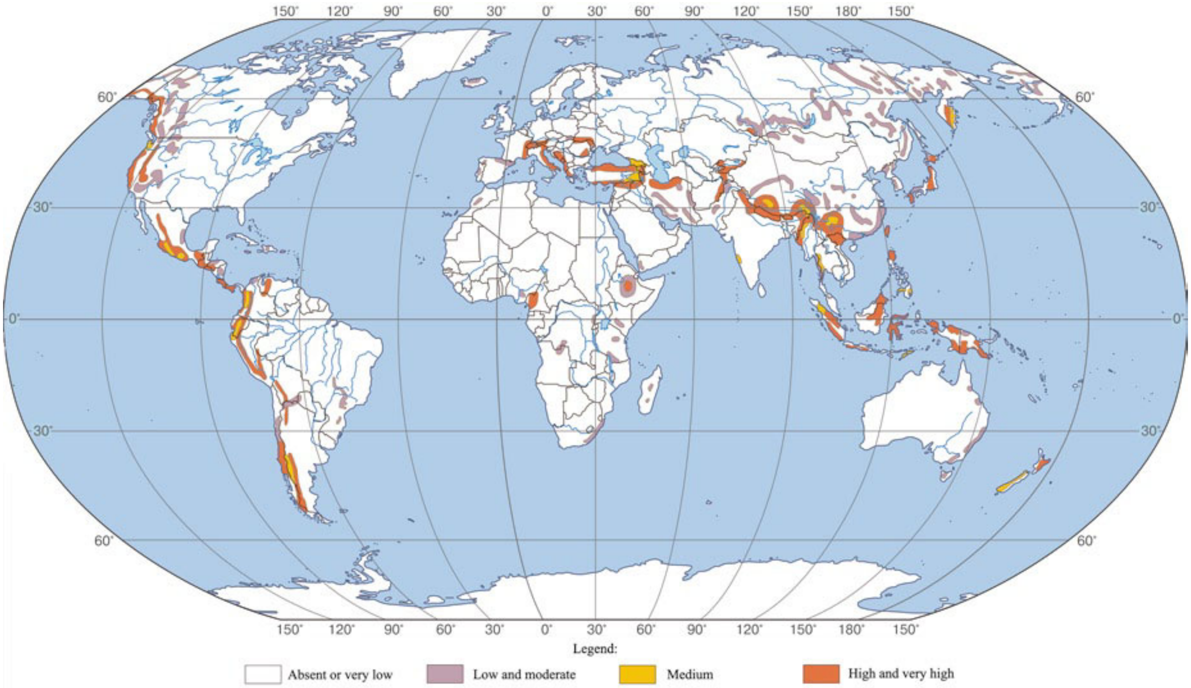

Fig. 2.2 Zoning of territory by the extent of the landslide hazard (Natural disaster hotspots 2006. Reproduced with permission of Norwegian Geotechnical Institute)

Photo 2.14 The impacts of landslides on a structure depend on the location of the object, which can be situated either within the landslide area or underneath it. The first situation is illustrated in this photo, showing displacement of a road by the *Feldweid* landslide near *Entlebuch, Lucerne, Switzerland* (Photo credit: M. Stauffer, Swiss Air Force, *23 August 2005*)

Photo 2.15 In case an object is situated underneath a landslide, negative consequences are caused by the dynamic impact of the moving mass and burial with landslide deposits. This photo shows a small landslide that blocked a road near Montagnier, Canton du Valais, Switzerland. The location has always been known for numerous landslides. One can easily trace the borders of earlier landslides by noting the areas covered with grass and young trees (Photo credit: H. Romang, MeteoSwiss, Switzerland)

Landslides create difficulties for many *kinds of human activity*. They especially endanger the following objects: (1) populated localities, (2) railroads, (3) motor roads, (4) bridges, (5) tunnels, (6) power and communication lines, (7) pipelines, (8) channels, (9) dams, (10) water storage reservoirs, (11) mining enterprises, (12) agricultural lands, (13) fishing areas, (14) water transport systems, and (15) forestry activities.

Events of landslide impacts on *populated localities* are numerous. For example, the Swiss town of Plurs was buried and 2,430 people were killed as a result of a landslide on 4 September 1618 (Restless landscape 1981).

In July 1938, landslides caused by heavy rains demolished more than a hundred thousand houses in one of the largest towns of Japan, Kobe; 600 people were killed (Natural disasters 1978). In 1971, a part of the small town of Saint-Jean-Vianney, Quebec (Canada), was demolished, 40 homes were destroyed, and 31 people were killed (Schuster and Highland 2001).

The influence of landslides on *rail transport* becomes apparent both in the immediate effects on the rolling stock and in damage to rail tracks and related infrastructure. *Two ways* landslides affect *rolling stock* are known: (1) immediate effects (shock action of the landslide mass or blockage with the deposit layer), and (2) train accidents due to collision with the landslide body or derailment of the train.

A *first-order* example is a landslide that occurred on 18 July 1948 on the 53 rd km of the Irkutsk–Baykal station railway line (where the Irkutsk storage reservoir is now located) when a minor landslide of 600–800 m^3 in volume struck the centre of a passenger train (Lomtadze 1977). A *second-order* example is a passenger train accident that occurred in April 1985, due to damage to a track near the town of Granby (Colorado, United States) (Landslides 1996).

Events when rail transport has been affected by way of damage to *rail tracks* are numerous. In 1906, landslides severed 5 km of railway to the south of San Francisco. A 2.1 million cubic metre landslide descending in Utah (United States) in the spring of 1983 seriously damaged several transportation arteries, including the Denver–Rio Grande railroad.

Photo 2.16 Landslides have intensive impacts on localities and thereby oftentimes claim multiple victims. The case shown here appears to be an exception. Timely evacuation saved the lives of inhabitants of a small settlement to the north of Santa Barbara, California (United States), though several buildings were destroyed (Photo credit: R.L. Schuster, U.S. Geological Survey, spring 1995)

Effects of landslides on *motor roads* are also widespread. For example, the Pan-American Highway suffers regularly from them. In 1986, landslides destroyed 18 km of this highway in Costa Rica. In January 2001, a 500,000 m^3 landslide blocked the highway in El Salvador, while, in March 1983, a landslide of one million cubic metres destroyed a section of this highway in Ecuador (Schuster and Highland 2001).

The influences of landslides on *bridges and tunnels* are worthy of further consideration. Tunnel entrances can be blocked by the deposit layer or shearing. The impact on bridges is defined as the pressure of the slump block on the shore piers. The effects on *transmission and communication lines* are similar to those on bridges.

Damage to *pipelines* is shown by deformation or breakage. For example, on 17 April 1999, breakage of the Yamburg–Yelets gas main pipeline with a subsequent gas fire occurred near the town of Sarapul (Udmurtia, Russia) (Atlas of natural and technogeneous dangers and risks 2005).

In many cases, landslides create difficulties for the laying and operation of *channels* through (1) undercutting, and (2) water table rise. For example, landslides created a whole array of problems during the construction of the Panama Canal and prevented it from becoming operational for many years.

Events when landslides have exerted influences on *hydraulic facilities* have not been infrequent. They

Photo 2.17 This photo demonstrates the impacts of landslides on railway transportation. This small landslide damaged a railroad near Granby, Colorado (United States) and thereby caused the train to crash (Photo credit: R.L. Schuster, U.S. Geological Survey, April 1995)

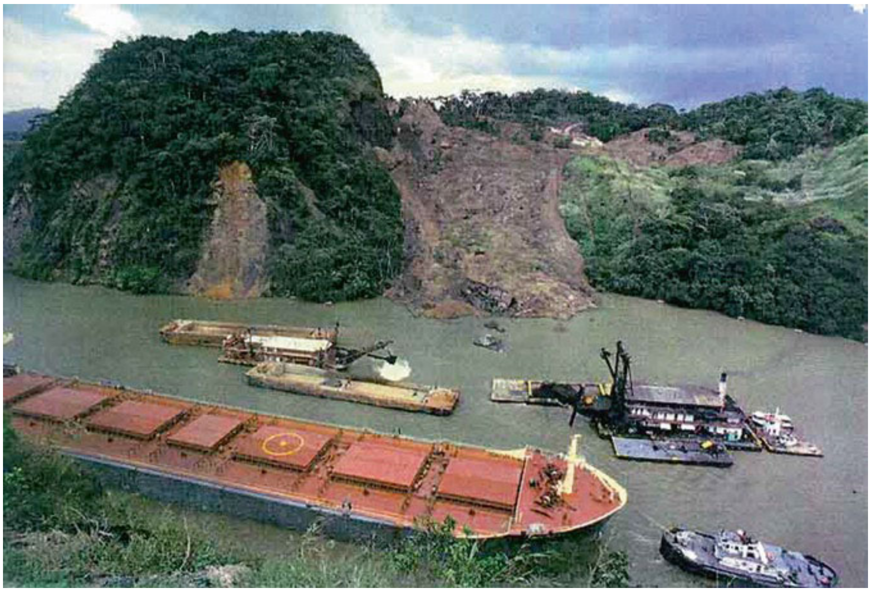

Photo 2.18 Landslides frequently aggravate the construction and operation of channels since they cut down slopes and raise the level of groundwater. In particular, they seriously complicated the digging of the Panama Canal and prolonged construction. Landslides increased the excavation volume by 55.5 million cubic metres. The landslides did not end with the completion of the Panama Canal. Workers repeatedly had to resume dredging for many years afterward. The photo shows one of the landslides that struck the channel (Photo credit: R.L. Schuster, U.S. Geological Survey, October 1986)

have immediate effects on hydroelectric dams, generator halls, and reservoirs. A power house in New Zealand completely collapsed in 1982, and damage to a hydropower plant in Romania in 1991 resulted in water supply disruption in Bucharest (Malik 2005).

In the literature, the *Vaiont landslide* in the northeastern Alps region of Italy has been described in numerous sources. This landslide occurred on 9 October 1963. It had a volume of about 240 million cubic metres and fell into the reservoir near a dam that is 265.5 m in height; the reservoir contained 120 million cubic metres of water. The rate of displacement was 15–30.5 m/s, and it lasted less than 30 s. The wave rose 100 m above the dam (without damaging it) and rushed down along a canyon. Over a period of 7 min, it destroyed the borough of Longarone and several villages. According to various data, 2,100–3,000 people were killed (Zaruba and Mencl 1979; Anderson and Trigg 1981; Howard and Ramson 1982; Kukal 1985).

As for *mining enterprises*, effects are exerted, first of all, on open cast mines and waste piles. The influence of landslides on *agriculture* is expressed as a reduction in area of arable and grazing lands due to burial with the deposit layer. In particular, large plots of agricultural holdings were made worthless as a result of the 1983 landslides in Costa Rica (Schuster and Highland 2001).

The impact on *fishing* can be seen as a worsening of environmental conditions in hydrobiont habitations (water pollution, destruction of spawning grounds, etc.), which leads to reductions in their populations and, accordingly, losses for this kind of activity. Investigations carried out in the Tomiki Creek basin (California, United States) showed that, as a consequence of a landslide, production of rainbow trout and salmon in this river decreased by 80%, which resulted in annual losses of about US$844,000 for fisheries in the early 1980s (Landslides 1996).

The influence on *water transport* is expressed as changes of depths in riverbeds or coastal zones of storage reservoirs, lakes, or seas, which create problems for navigation. In many areas, landslides make decisive contributions to deposits in riverbeds. For example, in the Mameyes River basin (Puerto Rico), the riverbed received 300 ton/km^2 of fragmentary material every year, and landslides accounted for 81% of it (Schuster and Highland 2001).

Landslides affect *forestry* to a considerable extent by destroying trees and creating problems with access to the felling sites. For example, the earthquake of 1976 in Panama activated a landslide in neighbouring Costa Rica that affected an area of 450 km^2. On 12% of this area (54 km^2), tropical forests were essentially destroyed. Large areas of woodlands were also demolished by widespread landslides in Ecuador (1987) and Colombia (1994) (Schuster and Highland 2001).

Considerable economic damage is caused by landslides in Japan, the United States, Italy, and India. The losses in Japan amount to about US$4 billion, while those for the three other countries are US$1 to 2 billion a year. Since problems with landslides exist in more than 100 countries in the world (Brabb 1991), *losses from landslides* reach US$10–15 billion a year (Govorushko 2007b). The average annual *mortality* is 600 people (Landslides 1996).

The influences of landslides on human activities are illustrated by Photos 2.14–2.18.

2.5 Submarine Landslides and Turbidity Currents

Submarine landslides do not infrequently cause the development of *turbidity currents* – currents near the bottom of seas and oceans that are saturated with suspended solids and are characterized by increased density. Submarine landslides and turbidity currents are characteristic of ocean regions where heavy bottom deposits do not possess adequate stability. In particular, they include the bottom near the mouths of rivers with great solid run-off. For example, about 50 turbidity currents are observed every year in the Congo River canyon (Neshyba 1991). The *speeds* of turbidity currents can exceed 90 km/h (Kennet 1987, vol 2).

Modern submarine landslides and turbidity currents produced by them influence the following kinds of *human activity and structures*: (1) harbour installations, (2) underwater communication cables, and (3) underwater pipelines. Submarine landslides can cause tsunamis, which are considered in Section 1.1.3.

Impacts on *harbour installations* become apparent when they are situated on top of the landslide block. The destruction of the harbour installations in the town of Valdez (Alaska, United States) is widely known. The town is located on the brink of a delta built by aqueous sand–gravel deposits. The earthquake that occurred on 28 March 1964 caused a landslide along the coastline. A sector of land 1,220 m long and 183 m wide crept down to the sea; the landslide volume reached 75 million cubic metres. Berths, related port infrastructure, and much of the shore dipped (Schuster and Highland 2001).

The effects of submarine landslides and related turbidity currents on *submarine cables* and *pipelines* result from the pressure exerted by the moving mass. A widely known example of this type is a submarine landslide and related turbidity currents that were created by the earthquake on 18 November 1929 near the Grand Banks of Newfoundland (North Atlantic). The landslide killed 27 people (Nisbet and Piper 1998). In turn, the landslide created a turbidity current. At first, it flew down along the continental slope by several canals and then united into a wide front (Kennet 1987, vol 2). The speed of the turbidity current reached 65 km/h (Nisbet and Piper 1998), and it travelled 720 km (Kennet 1987, vol 2). In the course of its movement, the turbidity current successively broke seven submarine communication cables (Vinogradov 1980).

Other events when submarine telegraph cables have been broken by turbidity currents were recorded near the town of El Asnam (Algeria) on 9 September 1954 (Aprodov 2000) and at the mouths of the Magdalena River (Colombia) and the Congo River (Encyclopaedia Ocean-Atmosphere 1983).

Submarine landslides can result in the formation of *tsunamis*. For example, in 1979, a landslide of 0.15 km^3 in volume near the airport at Nice (France) caused a tsunami that killed 11 people. In December 1951, a submarine landslide on the slopes of an oceanic trough off Puerto Rico generated a tsunami that resulted in considerable destruction on the coasts of Puerto Rico and Barbados (Kononkova and Pokazeev 1985).

2.6 Mudflows

A *mudflow* is a soil or soil-and-stone flow that emerges suddenly in the bed of a mountain river. The mudflow process is *characteristic* of more than 16% of the Earth's land surface (Fig. 2.3).

For the *formation* of a mudflow, the following *conditions* are necessary: (1) availability of loose or loosely coupled rocks in the watercourse channels and (2) availability of water with a volume and velocity that are sufficient to move these rocks (Sheko 1980). As for the *structure* – mud-and-stone, water-and-stone, mud, and water-gruss flows – the amount of hard material ranges from 10% to 75%. In nature, primarily the first two types of mudflows occur (Lomtadze 1977).

The water component of a mudflow can *originate* from a downpour, snowmelt, or breakthrough mudflows. The overwhelming majority of mudflows (80–90%) result from *downpours*. A record number of rainfall mudflows (up to 28 events a season) have been recorded in the Ganga River basin on the Yunnan Plateau, China (Natural-anthropogenic processes and ecological risk 2004). The remaining mudflows (10–20%) result from overflowing periglacial lakes and *summer melting of glaciers and snow*. Breakthrough glacial mudflows arise infrequently (in valleys with heavy glaciation once every 10–20 years); however, they become quite large (Myagkov 1995).

The origination and descent of mudflows take place within *mudflow basins*. Overwhelmingly, their areas range from 1–2 to 100–200 km^2, while the lengths of the watercourses range from 3–10 to 50 km. The *depths* of moving flows are generally 2–10 m, increasing to 15–50 m where the flow is constricted. The *speeds* of mudflows vary in the range of 2–10 m/s. Discharges reach 20–40 m^3/s for small watersheds and 2,000–10,000 m^3/s for large ones. The *duration* of the mudflow descent varies from several minutes to 3–7 days, but, most often, it is 1–3 h. The *volume* of fragmentary material that is moved varies from several hundred cubic metres in small slope basins to 3–6 million cubic metres in large mudflow basins of highlands. The *record value* of 11 million cubic metres was recorded in the Gusian River basin on the southern boundary of the Tibet Plateau (China) (Natural-anthropogenic processes and ecological risk 2004).

Mudflows mainly *affect* populated localities, motor roads and railroads, bridges, transmission facilities, canals, and cultivated lands (Govorushko 2007a).

The history of mudflows affecting *populated localities* goes back to ancient times. Very likely, the Alps are the first and main place on the Earth where civilization has met face to face with mudflows. In Tyrol (one of the Austrian lands, having an area of 12,600 km^2), beginning in the twelfth century, complete or partial collapses of populated localities have happened more than 30 times (Vinogradov 1980). In Austria, with an area of 83,800 km^2, there are more than 4,100 valleys with regular or episodic appearance of mudflows (Theoretical basics of engineering geology 1985).

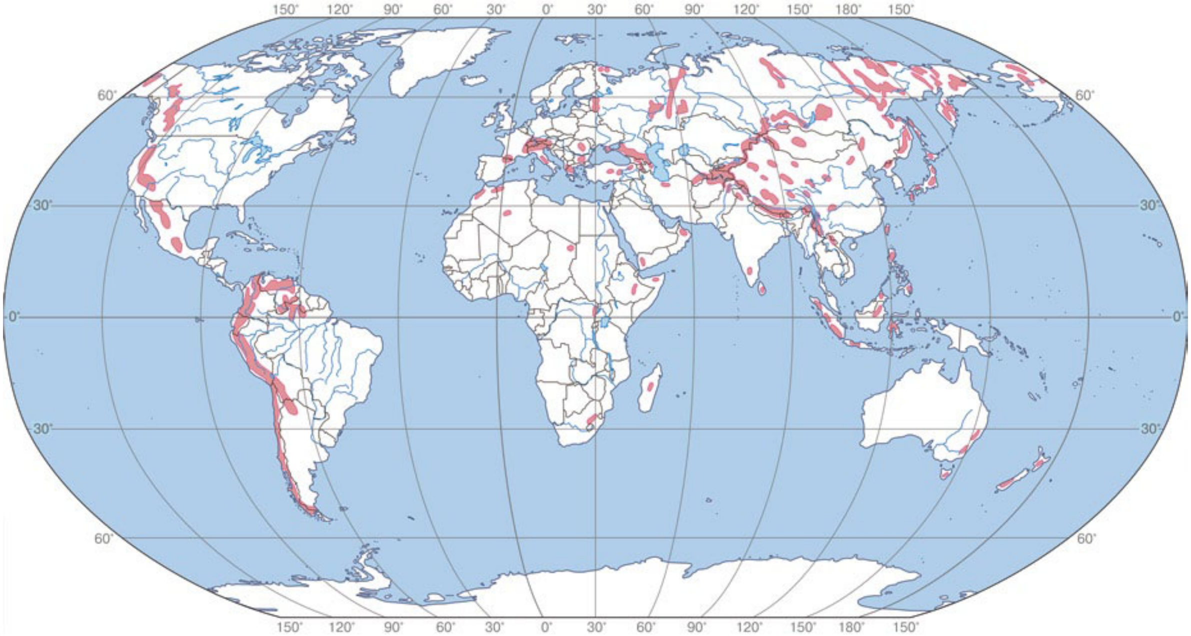

Fig. 2.3 Mudflow hazardous areas (Resources and environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of the Sciences)

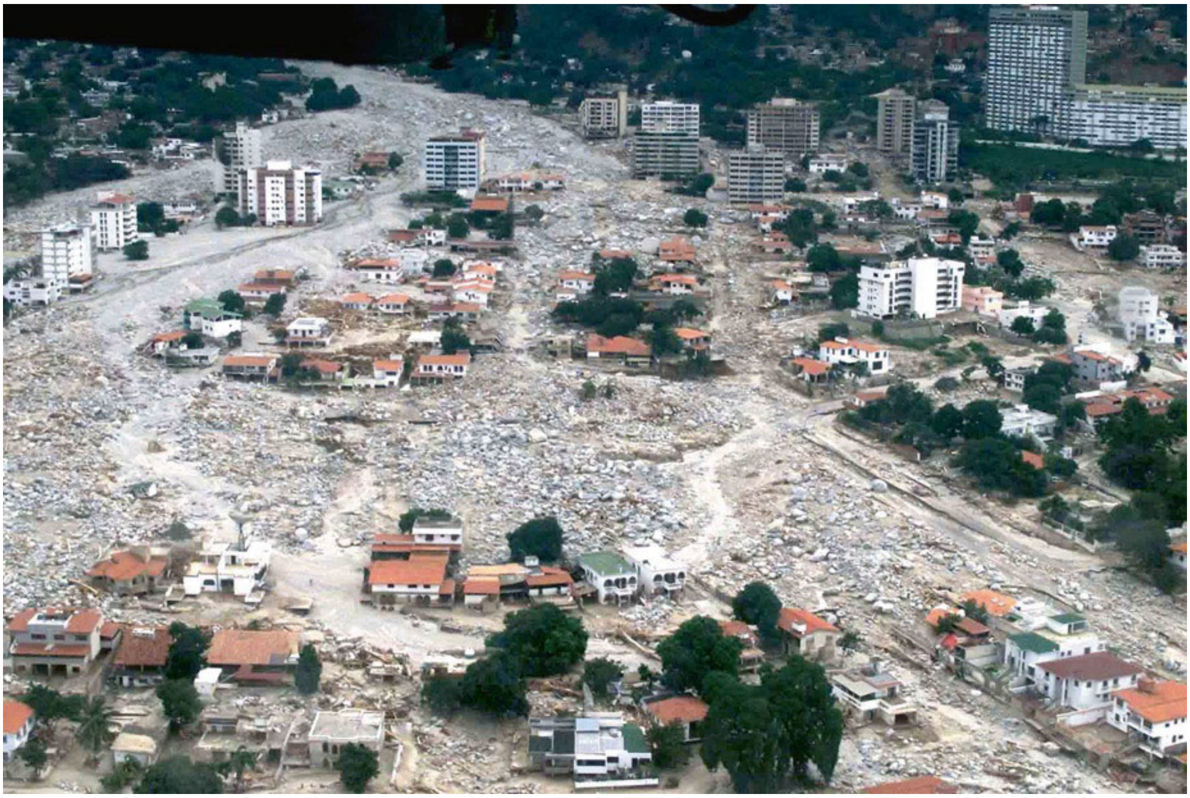

Photo 2.19 Heavy downpours (precipitation reaching 911 mm over 2 days, 14–16 December 1999) triggered a series of mudflows in the state of Vargas, the northern coast of Venezuela. Those mudflows killed 19,000 and caused US$1.9 billion in property damage. The photo shows the destruction in the city of Caraballeda. The volume of material transported by the mudflow is estimated at 1.8 million tons (Photo credit: Matthew C. Larsen, U.S. Geological Survey)

Photo 2.20 A mudflow of great power passed through La Guaira, 10 km west of Caraballeda. Its velocity exceeded 16 m/s. These boulders, which were moved by the mudflow, weigh 300–400 ton each (Photo credit: Matthew C. Larsen, U.S. Geological Survey)

The most catastrophic consequences of mudflows that have been noted occurred on 15–16 December 1999 in the Vargas state (Venezuela). The mudflows were provoked by extremely heavy precipitation: first, 200 mm of rain fell on 2–3 December, and 911 mm was recorded on 14–16 December. Total fatalities reached 19,000 people, while the financial losses were US$1.9 billion (Larsen et al. 2001). Landslides and floods contributed to these totals; however, just mudflows played a key role.

Mudflows have profound effects on *transport* (motor, rail, pipeline, water). When mudflows travel at high speeds, the roadbed *is removed*, together with the road embankment, under the pressure of transported material. At lower speeds, only *burial* of motor roads and railroads underneath a layer of deposits takes place.

The impact of a mudflow on *pipeline transport* results from the pressure of the mudflow mass on the supports and pipes, and it generally leads to destruction of the pipeline. The most large-scale event showing this effect was observed on 6 March 1987 in Ecuador, when, due to an earthquake, about 40 km of important oil pipeline in the country was destroyed by mudflows (Aprodov 2000).

The impacts of mudflows on *water transport* consist of changing depths, which creates difficulties for navigation. For example, mudflows regularly supply material to the Columbia River bed, which complicates the passage of ships to the town of Portland (Oregon, United States). To remedy the situation, dredging operations were carried out in the riverbed, in the course of which 34 million cubic metres of deposits of predominately mudflow origin were removed (Schuster and Highland 2001).

Mudflows often demolish *bridges* across smaller watercourses that are corridors for movement of materials.

Photo 2.21 A mudflow in 1949 killed thousands of people in Khait, Tajikistan. The 7.5 magnitude earthquake triggered the landslide (upper right corner), which in turn generated the gigantic mudflow. Several dozen houses were buried by fragmentary material (Photo credit: L.V. Desinov, Institute of Geography, Russian Academy of Sciences, August 1987)

For example, a mudflow in Los Angeles on 1 January 1934 damaged approximately 500 bridges (Larionov 1974).

The impacts of mudflows on *transmission* and *communication lines* generally include the demolition of towers and poles. For example, a mudflow descending in August 1977 to Alma-Ata (Kazakhstan) and having a total volume of six million cubic metres swept away 35 transmission towers (Esenov and Degovets 1979). The influences on *agriculture* are manifested as blockage with the deposit layer of tilled soil and pastures, removal of irrigation systems from service, and loss of livestock. At times, mudflows have destroyed *mining enterprises*.

The influences of mudflows on human activities are illustrated by Photos 2.19–2.23.

Photo 2.22 The effects of mudflows on motor transport are expressed as blockage of roadbeds with sediments and burial of vehicles. The photo shows cars buried by mudflow deposits in Brig, Canton du Valais, Switzerland (Photo credit: J.-P. Jordan, Federal Office for Water and Geology, Switzerland, 25 September 1993)

Photo 2.23 Protective measures against mudflows are varied. One of them is installation of flexible mesh barriers. The photo shows a flexible mesh barrier in the area of Aobandani, Japan, to protect against debris flow. It is 20 m long and 4 m high and is supposed to stop 750 m^3 of mudflow fragmentary material (Photo credit: Geobrugg AG – Protection Systems, Romanshorn, Switzerland, August 1998)

2.7 Rock Streams

Rock streams are large-scale accumulations of large rock debris that cover mountain slopes and flat tops.

Among the countries with *widespread occurrence of rock streams* are Russia, Canada, the United States, and Norway. They are also encountered in Sweden, Finland, New Zealand, mountainous regions of Italy, France, India, China, Chile, and other countries. The *conditions* necessary for rock stream formation are as follows (Govorushko 1986): (1) the presence of rocks that generate coarse-grained material in the course of weathering, (2) climatic conditions that contribute to this process, (3) the presence of a slope with steepness not exceeding the angle of rest, and (4) the occurrence of bedrock close to the surface.

As for the *feed sources,* two *types* of rock streams have been identified. The first type includes rock streams with *external* sources of feeding. They are formed by gravity-induced processes (rockfalls, screes) at the bottoms of scarp slopes. For rock streams with *internal* feeding, the macrofragmental material is obtained from bedrock subjected to weathering.

The spatial displacement of the rock stream material results from the slope (surface) movement of fragmental product and suffosion of silt under rock streams. The *reasons* leading to rock stream *movement* vary, but, more often, they are the different kinds of *creep*: *cryogenic* (displacement due to changes in deposit volume in the course of water freezing and ice melting), *thermogenic* (changes in the volume of fragments due to temperature variations), *hydrogenous* (changes in volume of silt due to changes in humidity), *suffosion*, and *plastic deformations of the ice-ground layer* (Govorushko 1986).

The *speeds* rock streams move generally range from millimetres to some centimetres a year, but sometimes there are catastrophic motions caused by different reasons (earthquakes, sharp ice thawing the rock stream mass during abnormally warm summers, etc.).

Rock streams affect the following *kinds of human activity and structures*: (1) motor transport, (2) rail transport, (3) hydraulic engineering construction, (4) mineral resource industry, (5) search for mineral deposits, (6) grassland farming, (7) populated localities, (8) building materials industry, and (9) water supply systems.

The effects on *motor roads* include pressure of the coarse-grained mass on road embankments, blockage of roadbeds with deposits, and washout of embankments by water discharge under rock streams, among others. Impacts on *rail transport* are similar to those on motor transport. In cases of disastrous movements, the consequences may be very serious. An example of such an occurrence is a freight train accident in the Severomuisky section of the Baykal–Amur Railroad (Russia) in 1990 (Exogenous geological dangers 2002).

Effects of rock streams on the volume of *water storage reservoirs* happen during the course of two processes of different directionality. The *first* process is a reduction in volume because a basin fills up with fragmental products and silt. The *second* is an increase in the basin volume when icy filling material melts out of flooded rock streams and the coarse-grained material subsides. Investigations carried out in the water storage reservoir of the Kolyma hydropower station (Russia) showed that, for its possible operating period, the effect of rock streams has been to increase the volume of the storage reservoir basin (Govorushko 2008b). As a whole, the effects of rock streams in changing the volumes of storage reservoirs are insignificant.

Rock streams have certain effects on *mining enterprises*. In addition to complicating the construction of the mines themselves, they have some impact on the volumes of *tailing dumps* – spots where barren rock that may be reworked in the future is accumulated. In the majority of instances, the effects of rock streams on tailing dumps result in an insignificant reduction in their volume (Govorushko 2007a).

Where they are present, rock streams leave traces *of mineral deposits*. On one hand, they create difficulties in the application of some search techniques (e.g. electrical exploration), while on the other hand, the peculiarities of rock stream dynamics can simplify the detection of mineral deposits. Suffosion under rock streams can selectively wash out fine ore matter from mineralized zones. As a result, material enriched with ore elements is carried out to the foot of a slope. A technique of searching for mineral deposits on slopes with rock streams is based on this. In valleys, samples of silt carried out from under rock streams are taken, and, based on increases in the content of useful components, ore bodies are found on the overlying slopes (Taisayev 1981). This technique is suitable for discovery of deposits of

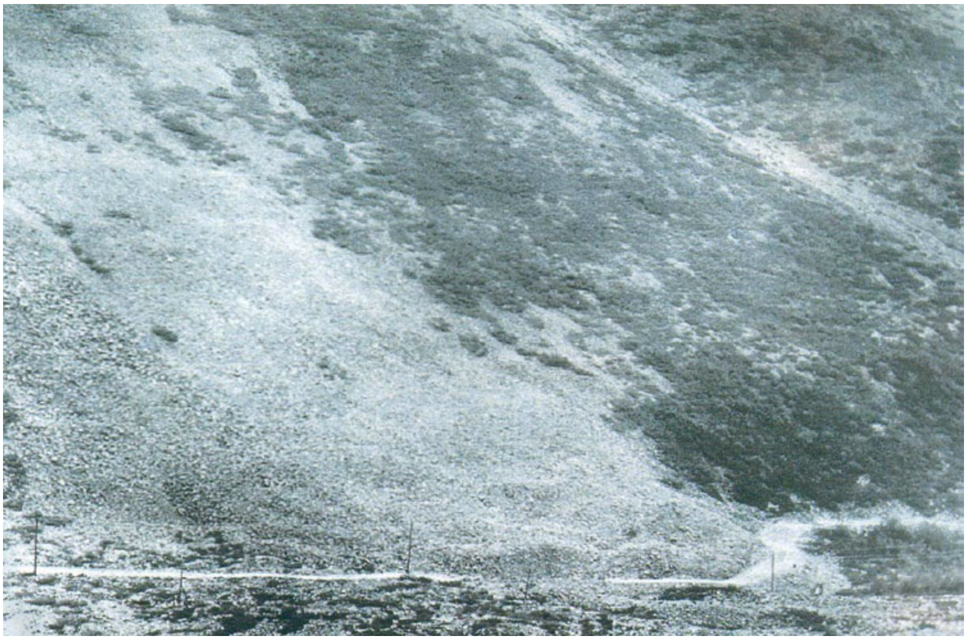

Photo 2.24 Rock streams oftentimes complicate the construction and maintenance of objects such as railroads and auto roads, and hydraulic structures. The photo shows a rock stream crawling upon a road near the Udokan mountain ridge, water basin of the Naminga River (Russia) (Photo credit: A.I. Tyurin, Department of Geocryology, Moscow State University, Russia, 1987)

molybdenum, nickel, copper, tin, tungsten, and other metals (Govorushko 1986).

To some extent, rock streams have impacts on *grassland farming*. They can destroy a soil layer, and grass cover, shrubs, and woody vegetation die out. Rock streams create problems for reindeer breeders: when a herd of deer crosses a rock stream, animals often break their legs (Geocryological dangers 2000).

For the present, there is no need to use territories where rock streams are present for purposes of *residential building*, although in the neighbourhood of the towns of Zlatoust and Katav-Ivanovsk (Russia), rock streams approached the domestic buildings, and, in a number of villages of the South Ural (Russia), they negatively impacted truck farming.

Rock streams can be used to supply *building materials*, *broken-stone ballast*, and, in certain cases, decorative facing material. They played an essential positive role in the construction of the Baykal–Amur Railroad when coarse deposits of rock streams were used to construct the roadbed. In addition, ice present in rock streams has been used for *local water supplies* (Govorushko 2008b).

The effects of rock streams on human activities are illustrated by Photo 2.24.

2.8 Aufeises

An *aufeis* is an icy body formed by freezing of water ejected to the surface from underground, river, and lake waters. The *process of aufeis formation* is characteristic of regions with severe climates. The largest aufeises are widespread in northern Canada and the United States (Alaska), Russia (basins of the Yana, Indigirka, and Kolyma Rivers), and Tajikistan (the Pamirs). In these regions, aufeises occupy up to 4% of the total area (Voitkovsky 1999). To the south of these regions, the sizes of aufeises are smaller, although their numbers slightly increase.

The following *conditions* are necessary for aufeis *formation*: (1) presence of surface or ground waters that rise to the ground or ice surface in wintertime, and (2) severe climatic conditions (low air temperatures, little snow, etc.). The *reason* for the ejection of water to the surface is water pressure rise due to winter freezing. For example, when ice is forming on a river and further increasing in thickness, the water pressure at the lower face of the ice increases. As a consequence, water breaks through the ice cover, spreads over the surface, and freezes, forming an aufeis ice layer. Water

Photo 2.25 Aufeises make roads slippery, which increases the number of road accidents. When an aufeis is not yet frozen on the top, cars bog down and freeze into ice if they stop. The photo shows an aufeis near the Udokan mountain ridge, the north of the Chita region, Russia (Photo credit: Y.A. Murzin, Institute of Permafrost Studies, Russia, October 1975)

ejection to the surface decreases the pressure in the system, and consequently, the water ejection ceases until the necessary conditions arise again. If the layer thickness does not exceed 8 mm, water freezes immediately. At greater thicknesses, an ice crust first forms at the surface (Voitkovsky 1999). The *annual volume* of aufeises on the Earth is about 1,000 km^3 (Atlas of the world snow-ice resources 1997, vol II, Book 2).

Aufeises can be dangerous to people. They also impact engineering facilities and different *kinds of human activity* (Govorushko 2008c): (1) motor roads and railroads, (2) transport, (3) populated localities, (4) mining enterprises, and (5) agriculture.

Explosions of ice crusts (aufeises) that occur when the water pressure force exceeds the roof strength can be dangerous to *people*. Quite often, such explosions are accompanied by ejection of very heavy ice blocks and powerful water flows. In 1932, an ice crust 2.5 km long and more than 100 m wide on the Zeya River (far eastern Russia) exploded with such force that it resulted in the deaths of several dozen people (Mazur and Ivanov 2004).

Impacts on *motor roads* and *railroads* include the *plugging of sag pipes* and *headways*. As a result, there is an abrupt water rise during the spring flood with subsequent washout of the *roadbed* and demolition of *bridges*. The repeated freezing–thawing of moisture accumulated in the base of road embankments can also cause deformations and destruction of the roadbed. For example, an aufeis on one section of the Baykal–Amur Railroad resulted in unacceptable deformation of railway track and, consequently, in traffic disturbances over a long period of time (Geocryological dangers 2000). In winter, when air temperatures are increasing, thermal expansion of aufeis ice can cause *bridge piers* to move upwards or downstream (Glaciological encyclopaedia 1984).

The impact of aufeises on *transport* becomes apparent in the increased numbers of *incidents* due to increased road slipperiness. Transport and road-building equipment stick and skid in unfrozen water from aufeises above them, and if they stop moving, they can instantly become icebound, which results in their removal from service.

Effects on *populated localities* can be seen in deterioration of the physical appearance of buildings, because building materials peel upon contact of the structures with aufeis. At times, buildings are filled up with aufeis ice.

Photo 2.26 Aufeises also block up water pipes and sewage outlets. Hence, in the springtime, water washes away roadbeds and destroys bridges. The photo shows melting aufeis in the vicinity of a bridge over O'Connor Creek in Goldstream Valley, northwest of Fairbanks in the Fairbanks D-2 Quadrangle, Alaska (United States) (Photo credit: R.D. Reger, 23 May 1984)

Photo 2.27 The impacts of aufeises on dwellings are widespread. Sometimes, buildings are filled up by aufeis ice from outside. This photo shows the reverse process. Melting of frozen ground underneath the houses made inside water gush out of the houses and form the aufeis (Photo credit: Department of Geocryology, Moscow State University, Russia)

Ice crusts (aufeises) represent a serious hazard for *mine workings*. They often form in adits and pit shafts, as well as at the surface where the mine water is discharged. Vast aufeises form around unplugged wells from which excess water is pumped and discharged to the surface. As a consequence, it leads to formation of thermokarst and waterlogging of nearby areas (Kotlyakov 1994).

There are two primary *ways* that aufeises affect *agriculture*. On one hand, they sometimes result in *depression of pasture herbage*, while on the other hand, the creation of artificial aufeises in river valleys can help conserve winter run-off, which makes it available during the growing season and raises the *productivity of crops*. Aufeises are a reliable indicator that ground waters are close to the surface, which at times is of great practical consequence for the *water supply*. Knowing an aufeis growth regime, one can plan the locations of water wells and recommend their operating conditions (Kotlyakov 1994).

The creation of artificial aufeises makes it possible to improve the *microclimate*, because where they are formed, the latent heat of ice formation is released in winter and absorbed in summer. Artificial freezing of water has been used for a long time in Siberia to make large refrigerated warehouses. Water is frozen to the walls and roofs of special buildings, and then the ice is covered with thick layers of sawdust, straw, plastic foam, etc., that insulate the aufeis from the outside air; the ice can be maintained for a long time and into the summer (Kotlyakov 1994).

The effects of aufeises on human activities are illustrated by Photos 2.25–2.27.

2.9 Aeolian Processes

Aeolian processes are relief-forming processes caused by winds. They *are distributed* throughout all natural zones of the Earth, but they prevail in steppes, semi-arid regions, and deserts. The global distribution of dust storms is shown in Fig. 2.4.

The following *conditions* are *necessary* for their initiation: (1) availability in the surface horizons of a considerable quantity of sandy and pulverescent particles, (2) the low cohesion of these particles, (3) wind strengths sufficient for particle capture and transport (vary from 4.5 to 12 m/s), and (4) bleakness of the surface or poor development of vegetative cover.

Depending on their specific weights, shapes, and sizes, particles move in *three ways*: (1) by *rolling* over the ground surface, (2) *by jumps* at a certain height, and (3) by transfer in the form of a *suspension*. The *amount of material* transferred by moving air is proportional to the third power of the wind speed (Dynamics and interactions of the atmosphere and hydrosphere 2004); for example, if the wind speed increases by a factor of 3, the amount of material that can be moved increases by a factor of 27.

In the course of wind transport, one can identify three *zones*: (1) blowing, (2) transportation of material, and (3) material accumulation. The *range* of material transport varies from several metres to many thousand kilometres.

The *tallest dunes* on Earth are in the Badain Jaran Desert, which is situated in northern China (Water source is under dunes 2005). These dunes are 300–400 m high. In coastal regions, the heights of dunes do not exceed 100 m (Larionov 1974). It is reasonable to conclude that the maximum height of aeolian forms of relief is determined, to a large extent, by the *thickness* of aeolian deposits. For example, the sand layer in the Takla-Makan Desert (China) has a thickness of about 300 m, while the sand layer thickness in the neighbouring Bei Shan Desert is only 20–30 m (Babayev 1983). The rates that the aeolian relief forms travel vary from 1 to 25 m/year.

Aeolian processes have pronounced effects on *human activities*. They are most dangerous to (1) populated localities, (2) people outside settlements, (3) agriculture, (4) transport, (5) bridges, (6) transmission facilities, and (7) telephone and satellite communications.

The history of *mankind* includes quite a number of dramatic pages related to aeolian processes. For thousands of years, the temples and structures of ancient kingdoms in Egypt were covered with sand and, in the course of several centuries, the mausoleums and palaces of Khorezm (Uzbekistan) were buried under sands (Maslov 1982). Sand drift within territories of Kazakhstan, Uzbekistan, and Turkmenistan during the fifth through eighth centuries forced nomads to move to the steppes of Europe (Myagkov 1995). More recently, more than a hundred residents of the village of Langmujie (central Tibet, China) were forced to leave the town because their homes were covered with sand (Liu and Zhao 2001).

Burial of *settlements* with sands is characteristic not only of deserts. In the Kurshskaya spit (Baltic Sea

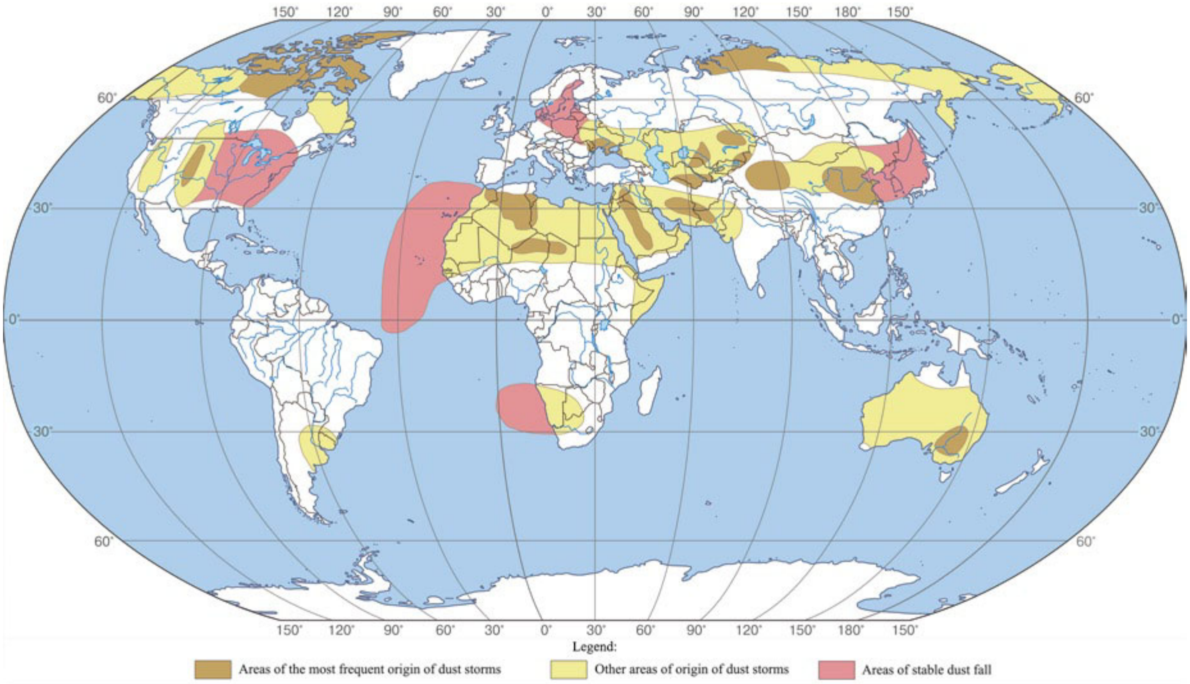

Fig. 2.4 Global distribution of dust storms (Gorshkov (2001). Reproduced with permission of Moscow State University, Russia)

coast), 14 villages disappeared when they were covered with drifting dune sands in the seventeenth through eighteenth centuries, and the town of Empuries on the Mediterranean coast of Spain was also covered with sand (Dolotov 1996). Many examples of the demolition of villages in France, Germany, and Latvia by dune sands are also known. Aeolian processes have other effects on populated localities as well. If these populated localities are within the blowing zone, house foundations may be *uncovered*.

Aeolian processes also affect *people* outside of settlements. Quite often, sandstorms have killed entire caravans. For example, 2,000 people and 1,800 camels were swept up with sand in 1805 during one such sandstorm (Mezentsev 1988). The loss in North Africa of a detachment 15,000 strong of the Persian king Kambiz is known (Chichagov 2005).

Important effects of aeolian processes on *agriculture* are as *follows*: (1) reduction in productivity due to removal of the fertile soil layer, (2) covering of crops and pastures with aeolian deposits, (3) notching of plant stems by transported soil particles, and (4) burial of irrigation channels.

The destruction of the *fertile soil layer* is a critically important impact. The dust storms of the 1930s swept away 25–75% of the topsoil over an area of 256 million hectares of the Great Plains in the United States (Gorshkov 2001). A single dust storm on 12 May 1934 swept away a soil layer 25 cm thick in the states of Kansas, Texas, and Oklahoma (Mavrishchev 2000). It is reasonable to conclude that the loss of the soil layer has a negative effect on crop capacity.

Disastrous effects on agriculture are infrequently caused by the opposite process. With *approaching dunes*, agricultural lands are removed from service practically forever. For example, beginning in 1980, 100 ha of cultivated land and 1,967 ha of green space in Zhanang County (Tibetan autonomous district, China) were completely buried with sands (Liu and Zhao 2001). Numerous events are known of burial of

Photo 2.28 Burial of objects with sand is typical not only of deserts but also of seaside areas. The photo shows a house being buried with sand along the coast of Oregon (United States) (Photo credit: H.J. Walker, Louisiana State University, United States, 13 May 1990)

fields and palm forests in the oases of the Sahara, the Kara-Kum, the Kyzyl Kum, cultivated lands on the Baltic Sea coasts, and near the town of Liepaja in Latvia (Larionov 1974). The *deposition of soil particles from the atmosphere* through aeolian transfer is also injurious to plants. When the deposits are thick, the crops may be entirely lost.

Another negative effect of aeolian processes on crop production is reduction in the crop yield as a result of *notching of plant stems* by jumping soil particles; part of the crop perishes in this case. Irrigation canals are often *filled with sand*, both due to intrusion of aeolian forms of relief and as a consequence of fall-out of particles from the atmosphere. In the *first instance*, run-off diversion systems are blocked, while in the *second*, channel capacity is reduced. In Xigaze County (Tibetan autonomous district, China), 5.8–6.8 km of irrigation main is damaged annually, and, in this case, the sand accumulation volume is 7–10 m^3/m of channel a year (Liu and Zhao 2001).

Aeolian processes have pronounced effects on all modes of *transport*. I.P. Gerasimov and T.V. Zvonkova (1978) describe the burial with sand of 500 m of *railroad track* in the western Kara-Kum in 1966. Burial of railroad beds with sand has also been noted on the coast of Chile (Dolotov 1996). The motion of sand dunes has often resulted in blockage of the 200-km railway between the towns of Walvis Bay and Swakopmund (Namibia). Attempts to fix the railway proved to be unsuccessful. The railway was moved a distance of 50 km to the continental part of the country, bypassing the sand dunes (Goudie and Viles 1997).

The situation with *motor transport* is similar in many respects. Aeolian processes cause a breakdown of transport communications, problems with engine ignition systems, and premature breakage of air filters. In the Tibetan autonomous district of China, every winter and spring, traffic over the highway to Nepal is interrupted. The total length of blocked sections is 4.8 km, but in this case, the sand thickness at three sections with an overall length of 1.5 km exceeds 1 m (Liu and Zhao 2001).

Effects on *air transport* are related, in the first place, to a *sharp visibility deterioration*, which has resulted

Photo 2.29 Dunes encroaching at speeds of tens of metres per year many times blocked the 200 km long railroad between Walvisbaai and Swakopmund, Namibia. The attempts to stabilize the movement of dunes by means of planting vegetation and constructing fences failed. As a result, the railroad was moved 50 km away from the dunes into the continental part of the mainland (Photo credit: A. Goudie, 1993)

in plane crashes. On 2 March 1981, a helicopter carrying the Egyptian defence minister, Gen Ahmed Badawi, came into a dust storm near the Siwa Oasis (Egypt). The helicopter hit a lamp post and overturned just after lifting off. The Egyptian defence minister and 13 senior officials were killed in the crash (Kovalevsky 1986). In November 1962, the airport at Cairo (Egypt) was closed for some days due to a dust storm. In addition, owing to the high dust content in the air, premature wear of engines occurs.

Effects of aeolian processes on *water transport* also include *visibility deterioration*. Sometimes, dust storms make navigation impossible. For example, in November 1962, navigation through the Suez Canal was halted due to a dust storm in the Arabian Desert. The influences of aeolian processes on water transport also include changes in the depths of water within the coastal zone. For example, the movement of dunes across the Kurshskaya spit led to *burial* of the Klaipeda Port fairway in Lithuania (Dolotov 1996). Aeolian processes also uncover sizeable sections of *pipelines,* leading to rapid damage to pipeline sheathing and even pipe breaks.

Transmission facilities and *bridges* are affected when sand is swept away by the wind, which uncovers the bases of bridge abutments and transmission towers. Other effects are due to the abrasiveness of particles. At high rates of sand movement, the abrasive force becomes significant (the use of *sand blasters* in engineering is based on this behaviour). For example, telegraph poles in California (United States) were 'sawed' by sand in the course of a year (Kotlov 1978). The abrasive effect of particles is also a reason for the failure of *wire insulation*.

Dust storms generate serious interference in *radio communication*, because through friction against the air or ground, the dust particles acquire a considerable electric charge, which can create a static charge on radio antennas (Encyclopaedia Ocean-Atmosphere 1983). In addition, dust storms appreciably reduce *satellite communication* quality (Goudie and Middleton 1992).

In some cases, aeolian processes can be *useful* to people. Dunes can be used for construction of *golf courses*, *sand recovery*, *recreational facilities* (pathways for walking, bicycling, riding), *construction of campsites*, and other purposes (Goudie and Viles 1997).

The *economic damage* due to aeolian processes is colossal. It is caused by numerous factors, the *most significant* of which are (1) decreases in soil fertility,

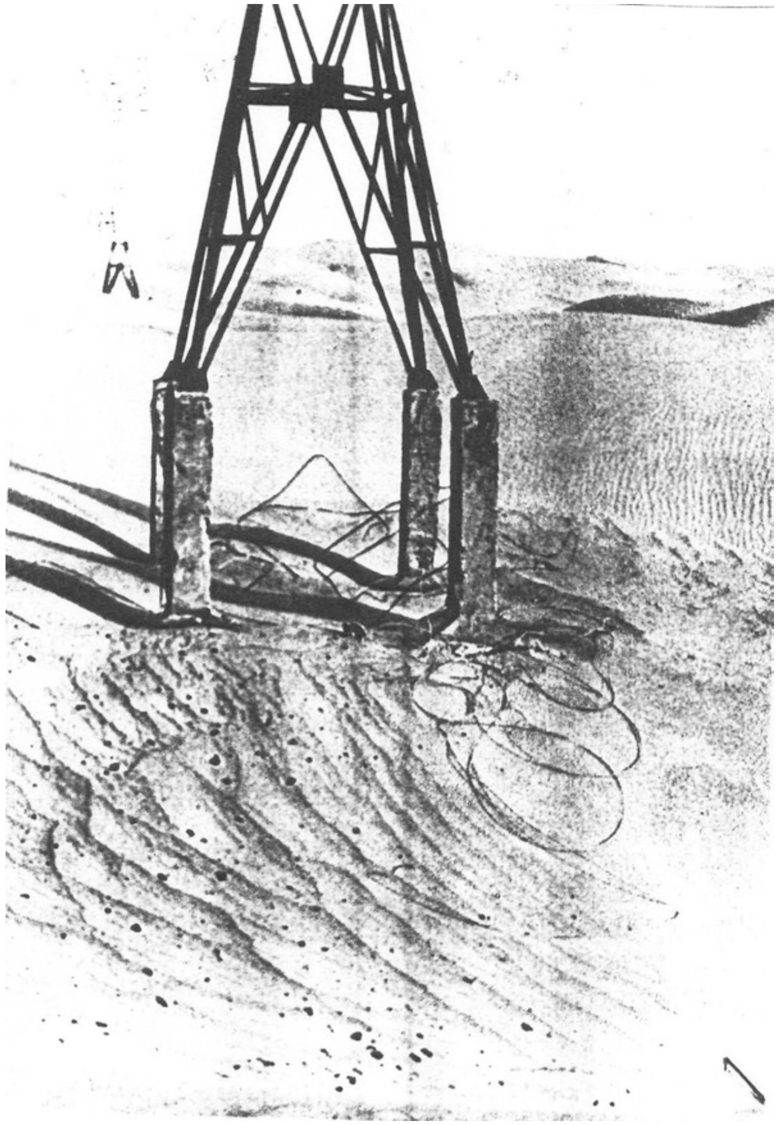

Photo 2.30 The shift of sediments within arid erosion area leads to various negative results, such as exposure of house foundations and electric power pylons. The photo shows sand blowing off electric power pylons in Karakum (Photo credit: E.L. Ryabikhin, The National Institute of Deserts, Flora and Fauna, Turkmenistan, 1989)

(2) blowing and burial of crop plants, (3) notching of plants by jumping soil particles, (4) filling of irrigation channels, (5) interruptions in the operation of transmission facilities, pipelines, and bridges due to the ground blowing from under the piers, and (6) premature wear of automobile and aircraft engines due to dustiness. The *approximate losses* caused by aeolian processes can be estimated at US$5–7 billion/year (Govorushko 2007c).

The influences of aeolian processes on human activities are illustrated by Photos 2.28–2.32.

Photo 2.31 Aeolian processes greatly contribute to desertification. Thus, 22.7% of Africa suffers from desertification. This photo shows the Ntekem–Kempt Oasis in Mauritania, which is beset by sands (Photo credit: U.N. Food and Agriculture Organization, image 18832 by I. Balderi, 1995)

Photo 2.32 In the control of aeolian processes, biological methods, especially the setting of plants, to stabilize the sands are of great importance. The photo shows dunes stabilized by vegetation planted in central Niger (Photo credit: U.N. Food and Agriculture Organization, image 18876 by F. Paladini and R. Carucci, 1989)

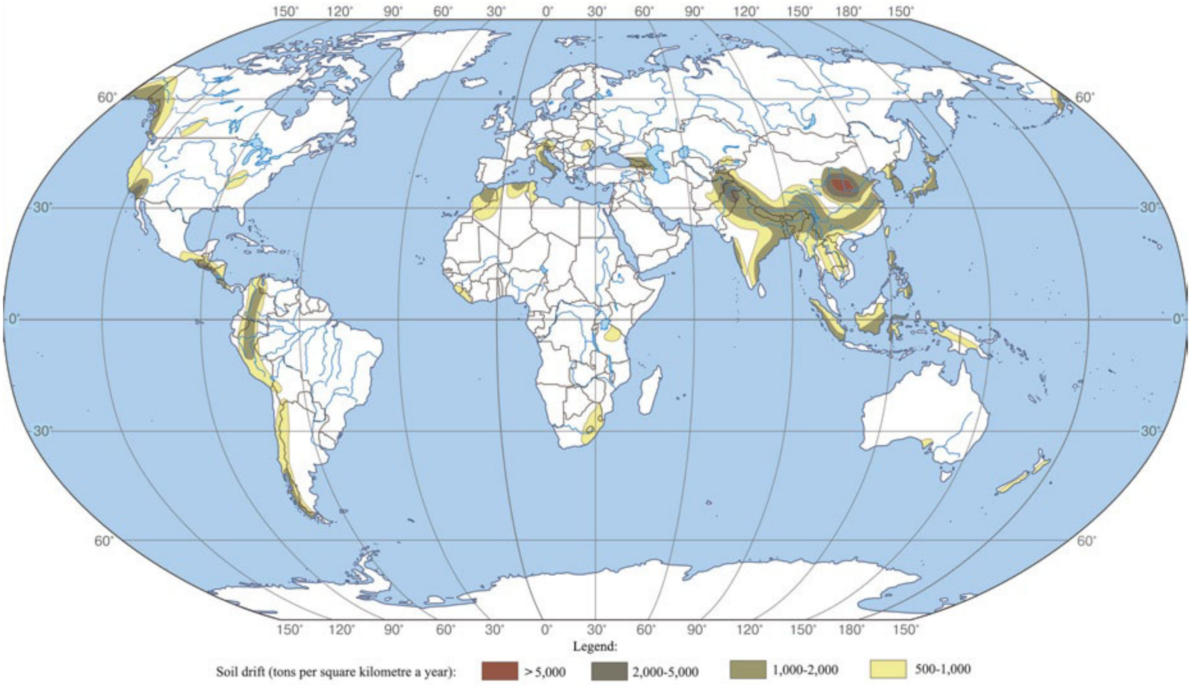

Fig. 2.5 Territories with maximum development of soil erosion (Resources and environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of the Sciences)

2.10 Soil Erosion

Soil erosion is the destruction of soil and underlying rock by surface waters. Soil erosion is extremely *widespread* (Fig. 2.5).

Among the *main factors* determining the development of soil erosion can be (1) precipitation (amount and rate), (2) characteristics of a slope (length, steepness, and orientation to north), (3) vegetation, and (4) soil features.

Depending on the water supply source, *three categories* of soil erosion have been identified: (1) erosion caused by snowmelt run-off, (2) erosion due predominantly to storm run-off but with participation of snowmelt waters, and (3) erosion due to heavy showers.

The water erosion of soil is subdivided into *linear (gully) erosion* and *sheet washing*. In gully formation and development, *four stages* have been identified (Tanasiyenko et al. 1999).

The *first stage* is the formation on the soil surface of a scour or a hole 35–45 cm, rarely about 1 m, deep in which the flows of meltwater and rainwater are concentrated. Its longitudinal profile follows the profile of the slope, and the mouth is often hanging; that is, it is located high above the slope base. After this stage, there is an annual scour deepening with a gradual transformation into a real gully.

The *second stage* is the cutting of a gully head. In the course of the flow of meltwater and rainwater to the upper part of the gully, a water jet is divided with the formation of numerous splashes, which intensively moisten the gully walls. The over-moistened loose rocks on the walls begin to swell and fall down to where the water flow crushes and takes them away. With the lapse of time, a niche growing in breadth and length is formed in the front wall. Finally, under the action of gravity, a cornice consisting of soil horizons falls down.

In the *third stage,* active growth of a gully lengthwise with simultaneous deepening and broadening is observed. During this stage, fresh, unmatted slopes with extensive development of downfall and sloughing processes are characteristic. At the gully entry, a debris cone is formed on the surface where much of the rock carried away by the water accumulates yearly. As a consequence, the junction part of the gully flattens out little by little, helping to stabilize the slopes. In the

Photo 2.33 The effects of ravines on human activities are evident in the widening and extending of ravines. The photo shows damage to a road due to lateral erosion at Roten Bach, Switzerland (Photo credit: E. Gertsch, Institute of Geography, University of Berne, Berne, Switzerland, 5 August 2004)

gully bottom and the lower parts of the slopes, the first vegetation appears.

The *fourth stage* of development (damping stage) comes when the longitudinal profile of a gully approaches equilibrium. At this time, erosion at the bottom stops, the angles of the slopes decrease, and the edges flatten out. With increases in grass growing on the slopes and at the bottom, the loss of soft rocks is reduced. After the slopes and the bottom are completely covered with grass, the loss of fine-grained soil decreases drastically, and further changes proceed over a period of several centuries or even thousands of years.

Gullies grow at rates ranging from 0.05 to 100 m/year, being on average 1–3 m/year, depending on local conditions. If the lifetime of a gully is considered to be 100%, then the loss of 35% of the total volume of material takes place during the initial 5% of the lifetime. The growth of the gully essentially stops after a lapse of 60% of the lifetime (Tanasiyenko et al. 1999).

Sheet erosion is observed wherever there is heavy precipitation. The rate of sheet erosion is measured by the mass of material removed per unit area or by the thickness of the layer removed on average during a year. The *natural intensity* of the sheet erosion in the inter-stream areas of the plains of the temperate climate zone is several hundredths of a millimetre per year; an erosion rate of about 0.5 mm/year corresponds approximately to the rate of the accumulation of humus in soil, while at higher intensities, the productive layer is reduced (Myagkov 1995).

For the world as a whole, water erosion processes *remove* about 23 billion tons per year from arable lands, including the following countries (in billion tons): India, 4.7; China, 3.3; former USSR, 2.3; the United States, 1.5; and the rest of the countries, 10.9 billion tons per year (Gorshkov 2001).

Soil erosion affects many *kinds of human activity* and things of economic importance (Govorushko 2009b): (1) agriculture, (2) motor and rail transport, (3) transmission and communication lines, (4) pipelines and underground facilities, (5) populated localities, (6) ponds and storage reservoirs, and (7) water supply systems.

The effects of soil erosion on *agriculture* are extensive and take the following forms: (1) burial of lands as a result of deposition on them of products of gully fan and sheet flooding, (2) dissection of lands as a result of gully formation, (3) reduction in yields of arable crops, and (4) filling-in of irrigation channels with products.

The *burial* of valuable agricultural lands with gully fan products occurs on a wide scale. For example, about 800 gullies have been counted in one of the districts of Novosibirskaya oblast (Russia). Yearly, more than 128,000 m^3 of soils and soil-forming materials are removed from them. By now, 509 ha of cultivated lands have been removed from service (Tanasiyenko et al. 1999).

Photo 2.34 Formation and growth of ravines influence pipeline transport. The photo shows the exposition and deformation of oil pipelines in the Yelabuga district of the Republic of Tatarstan (Russia), in the course of ravine development (Photo credit: V.A. Yelkin, 26 August 2001)

The *dissection of lands* as a result of gully formation is an important effect of erosion on agriculture. The linear growth and extension of gullies result in loss of cultivated lands. For example, there are 214 gullies within the catchment area of the Novosibirsk oblast storage reservoir, and they have destroyed 178 ha of farmland (Tanasiyenko et al. 1999). In addition, the dissection of lands creates difficulties in the use of farm machinery.

The development of erosion has serious effects on soil fertility and, accordingly, on the *productivity* of crops. Reduction in the soil layer depth decreases the available moisture capacity and the thickness of the layer in which root systems can develop. As a result of the washout of organic material, the moisture-retention properties of the soil lessen. In the event of raindrop erosion, soil consolidation and encrustation occur quite often, which have adverse effects on seed sprouting and plant establishment. Severe erosion can cause the massive loss of seeds (Goudie 1997). When a soil is washed away, from 10% to 30% of the introduced fertilizers and pesticides are removed from the ploughed fields (Kuznetsov and Glazunov 1996).

Nevertheless, the *main cause* of loss of fertility is the *removal of nutrients* and many chemical elements needed for plant growth. For example, throughout Russia, 40 million tons of humus, 18.6 million tons of potassium, two million tons of nitrogen, and 1.1 million tons of phosphorus are lost (Ecological encyclopaedia 1999). Soil erosion results in significant *lowering of crop yields*. In the United States, for example, crops that are grown under conditions of considerable erosion include 24% of corn, 26% of soybeans, 21% of cereal crops, and 16% of feed crops (Agricultural ecosystems 1987). The removal of loose material due to gully (ravine) erosion and sheet flooding also results in blockage of *irrigation canals*.

Gullies have adverse influences on *motor roads and railroads*. It is necessary to construct bypass roads, which increases distances that must be travelled. Gullies destroy roads or block them with loose sediments; therefore, it is necessary to build numerous engineering structures. Originally, there were three bridges over a 24-km distance between the cities of Alatur and Arbatov in the Middle Volga Plain (Russia). Forty years later, their number had increased to 42 (Lomtadze 1977). The influences on other line structures (*transmission and communication lines, pipelines, underground facilities*) are very similar. The selection of their routes is complicated; scour damage of towers and poles, uncovering of underground facilities, and so on, take place.

Soil erosion has important effects on *populated localities*. In archaeology, 'the Dead Cities' (a group of 700 abandoned settlements in north-west Syria between Aleppo and Hama) are widely known. They were

Photo 2.35 The impacts of ravines on dwellings lie in the partitioning of territory and its filling with the products of ravine formation. The photo shows vertical and lateral erosion in a stream channel in a settlement in Val Valdun, Rueun, Canton du Grisons, Switzerland, which threatens houses (Photo credit: H. Romang, MeteoSwiss, Switzerland, 2002)

Photo 2.36 Soil erosion is an urgent problem for Lesotho. The country yearly loses 1% of arable lands due to soil erosion. Excessive pasturing of cattle, in addition to periodic draughts and inundations, greatly contributes to it. A woman farmer who grows fruits and vegetables in southern Lesotho is standing at the edge of a deep ravine that is destroying her vegetable plot (Photo credit: U.N. Food and Agriculture Organization, image 19247 by P. Lowrey, 1995)

devastated by soil erosion, and the underlying limestone was exposed over an area of 405,000 ha (Legett 1976).

Soil erosion also has negative effects on the condition of *ponds and small storage reservoirs*. There are increases in *turbidity* and decreases in the reservoir basins' *volumes*. These events result in decreases in *energy* generation and reductions in the *fish capacity* of the reservoirs, which in turn influence the cost

Photo 2.37 Another impact of soil erosion on plant cultivation is coating of arable lands with products of ravine outwash and sheet erosion. The photo shows sediment from sheet and rill erosion covering crops in a field at the base of a hill in Iowa (United States) (Photo credit: Keith McCall, USDA Natural Resources Conservation Service, 1999)

efficiency of *aquaculture* facilities. The *quality of water* used for drinking and economic purposes deteriorates. Another effect on water supplies is as follows: Opening and draining the water-bearing horizons, they deplete groundwater resources and adversely affect *water supply* sources. For example, the intensive erosion in the Bijie prefecture (Chinese province of Guizhou) has involved 63% of its territory. As a consequence, a third of the wells had no water (Zhang 1999).

As for *economic damage*, a detailed assessment was carried out for the island of Java (Indonesia). Here, the total damage caused by soil erosion reaches US$373 million a year. The damage is distributed as follows: agriculture, US$315 million (84.5%); silting of storage reservoirs, US$46 million (12.3%); silting of irrigation canals, US$10 million (2.7%); and dredging operations in ports, US$2 million (0.5%) (Magrath and Arens 1989). On a global scale, the amount can be estimated at US$18–20 billion (Govorushko 2009b).

The effects of soil erosion on human activities are illustrated by Photos 2.33–2.37.

2.11 River Erosion

River erosion is the washout of channels and banks by streams. To a greater or lesser extent, erosion is natural for any river, so it's no wonder that the process is very widespread. The *erosive capacity* of a river is determined by its *kinetic energy*, which is calculated as half the water mass multiplied by the square of the velocity of its current. Water mass is proportionate to water flow, that is, the amount of water passing through a point per unit of time. Flow velocity depends on the slope of a channel. Thus, the *greater* the water flow and the *steeper* the inclination of the channel, the more erosive capacity the river possesses.

River erosion is a result of deep and lateral erosion. *Deep erosion* means vertical penetration of water flow in strata, while *lateral erosion* is understood as the horizontal shift of a riverbed caused by the washout of banks. Both kinds of erosion act simultaneously; however, lateral erosion continues even when deep erosion ends and gives way to accumulation.

Photo 2.38 Riverbed erosion has various impacts on dwellings. One of the major factors is damage and destruction of houses owing to riverbank cut-offs. The photo shows a house in British Columbia, Canada, that is being destroyed due to intensive lateral erosion (Photo credit: H.J. Walker, Louisiana State University, United States, 1967)

Humankind has been dealing with river erosion since ancient times. It has mainly negative impacts on many man-made objects and *human activities*, such as (1) settlements, (2) bridges, (3) transportation, (4) water reservoirs, (5) agriculture, (6) the mining industry, and (7) international relations (Govorushko 2009a).

Settlements are impacted by several *means*. Buildings are damaged by *lateral erosion*. Settlements are displaced subsequent to the migration of river flows because of *riverbed alterations*. Settlements located next to large river deltas may become *waterlogged*. *Accumulation of sediments* can lift a riverbed above adjacent territory, while intensive bottom erosion makes a river *penetrate deeper* into the ground.

Bridges are affected by both lateral and bottom erosion that threaten bank supports. *Shipping* suffers as a result of bottom erosion and accumulation. Changes in water depth complicate *navigation*. Lateral erosion either damages *port structures* or shifts them away from a riverbed due to degradation of the opposite bank. If an offshore strip is shallow, this leads to the shifting of estuaries. Not infrequently, due to sediment accumulation, ports end up being situated far from the sea. River erosion also impacts *pipeline transport*. Accumulated sediment exerts mechanical pressure on underwater crossings, and degradation of banks causes problems if pipelines are constructed along riverbeds. Impacts on *automobile roads* and *railroads* are similar to those mentioned above and are caused by lateral erosion.

River erosion seriously impacts *water reservoirs*. As a result of hydrological regime changes, all transported deposits and most suspended sediments remain in water reservoirs. The *total weight of sediment* accumulated in water reservoirs on our planet amounts to 13.4 billion tons per year (Yasamanov 2003). This process diminishes the *useful capacity* of water reservoirs. In some cases, this is a galloping process. The Sanmexia water reservoir on the Huang He River (China) serves as a perfect example of that kind of process. The dam construction was over by 1960, but in 4 years, the water reservoir was almost totally filled with sediment (Lakes and reservoirs 2000).

Plant cultivation and *animal husbandry* are impacted when riverbeds wander along sub-mountain deltas away from agricultural oases located on them. Fields and pastures also suffer from bank degradation if they are located nearby, water intake works used for irrigation can be damaged, and other adverse impacts can take place.

Photo 2.39 Impacts of riverbed erosion on auto roads and railroads are, in most cases, exerted through lateral erosion too. The photo shows the destruction of a roadbed as a result of riverbank cut-off in Kyrgyzstan (Photo credit: Marli Miller, University of Oregon, United States)

Photo 2.40 The impacts of riverbed erosion on plant cultivation lie in the diminution of agricultural lands due to riverbank cut-offs. The photo illustrates intensive lateral erosion on one of the Brahmaputra River channels in Bangladesh; the main riverbed is 4–5 km away. The cultivated plant is rice that is currently in the stage of ripening, 5–7 days before harvest (Photo credit: Nazmul Islam Chowdhury, 26 November 2005)

River erosion has favourable effects on the *mining industry*. Minerals transported by water accumulate, forming deposits of gold, platinum, and cassiterite. Alluvial gold deposits account for a large portion of the total extraction of this metal. Alluvial sediments such as sand, gravel, and pebbles are often used as ballast, building material for concrete manufacturing, and drainage ground for earthworks.

River erosion affects *diplomatic relations* as well. In many cases, political borders pass along rivers, and when riverbeds change direction, some areas may turn out to be located in another country or state. Such occurrences often result in political and even military conflicts. More often, problems arise due to bank washout. Displacement of riverbed can increase the territory of some countries and decrease the territory of others. Specifically, such difficulties are typical for the Russian–Chinese boundary in the vicinity of Khabarovsk and for the North Korean–Russian border in the southwest of the Primorsky krai (Govorushko 2007d).

The effects of river erosion on human activities are illustrated by Photos 2.38–2.40.

2.12 Abrasion

Abrasion is the destruction of shores and nearshore bottom areas of the great water bodies (seas, lakes, storage reservoirs) by waves.

This process is widely *distributed* (see Fig. 1.5). The length of shores subjected to marine abrasion (not including thermal abrasion) has been estimated at 160,000–170,000 km for the whole world. Data concerning the volume of material eroded due to marine abrasion conflict. The figures cited differ by almost two orders of magnitude and range from 0.2 to 14.7 billion tons per year; values of 2–3 billion ton per year seem to be more accurate.

The *major source of energy* for the destruction of shores is the energy of wind-generated waves, while tides are of secondary importance. Other sources (tsunamis, seiches, etc.) play third fiddle. *Three types* of abrasion have been identified: (1) mechanical, (2) chemical, and (3) thermal.

In the case of *mechanical abrasion*, rocks are broken by the hydraulic impact of the swash, instantaneous compression and decompression of the air in rock fractures, and also as a result of bombardment and abrasion of the rock by fragmental products. According to S.M. Myagkov (1995), the impact force can reach 70 ton/m^2. Once during a gale in a bay in Scotland, a stony massif with a mass of 1,370 ton was displaced over a distance of more than 10 m (Maslov 1982).

The impact of *chemical abrasion* is determined by solubility of a rock in water; it is characteristic of shores formed by limestone, halite, dolomite, gypsum, and other rocks.

Thermal abrasion – that is, thermoabrasion, the process of destruction, due to the thermal action of water, of shores formed by frozen rocks or ice – was considered earlier, in Sect. 1.2.2.

The *intensity* of abrasion is determined by the following *factors*: (1) rock strength and resistance, (2) the openness of the water body, (3) prevailing wind direction, (4) depth of the coastal zone, (5) tidal regime, and (6) climatic peculiarities of the area. The *greatest contribution* is made by mechanical abrasion, and the most realistic estimates of rates of chemical abrasion, according to G.A. Safyanov (1987), are only 0.5–5.0 mm/year. The energy of waves is proportional to the square of their height; therefore, most abrasion is caused by large waves (Myagkov 1995).

Rates of *shore retreat* vary widely – from several centimetres to tens of metres a year. For example, the retreat of sea cliffs in the Holderness peninsula (England) on the North Sea coast is, on average, 2 m/year (Encyclopaedia Ocean-Atmosphere 1983); the rate of shore shifting around Primorsko–Akhtarsk on the Sea of Azov reaches 15 m/year (Exogenous geological dangers 2002); while, on the western coast of France (Médoc peninsula), it is 15–35 m/year (Yasamanov 2003). In some extreme events, the degradation rates can be well above these figures. On the coast around Miami (state of Florida, United States), one hurricane in 1926 moved the shore by 70 m, while, in 1961, a retreat on the Matador Peninsula (state of Texas, United States) reached 250 m (Myagkov 1995).

Abrasion results in the loss of land. It also affects many economic entities and *kinds of human activity*: (1) water transport, (2) recreational activities, (3) residential development, (4) motor roads and railroads, (5) pipelines, etc.

As an example of the *loss of land*, one can cite Helgoland Island in the North Sea. Over a period of 1,000 years (AD 900 through 1900), the perimeter of the island decreased from 200 to 5 km, and the area decreased by 885 km^2; in other words, yearly rates of

Photo 2.41 The coast retrogression rate in the case of abrasion depends on many factors (e.g. strength and hydro-resistance of rocks, depth of the coastal zone, and prevailing wind directions) and varies within a wide range: from several centimetres to hundreds of metres a year. The photo shows an eroding cliff adjacent to a three-storey coastal house in the town of OceanLake, central Oregon coast (United States) (Photo credit: H.J. Walker, Louisiana State University, United States, 13 May 1990)

Photo 2.42 The effects of abrasion on engineering structures are caused by the undercutting of bank slopes and their subsequent collapse. This road on the coast of the Adriatic Sea, Barletta, southeast Italy, was destroyed by abrasion (Photo credit: H.J. Walker, Louisiana State University, United States, 7 April 1987)

territory loss were 0.9 km^2 (Yasamanov 2003). In Russia, abrasion leads to the loss of 5,000 ha of coastal lands every year (Lukyanova et al. 2002).

The effects of abrasion on *water transport* are due to two *factors*: (1) beach drift and (2) stream-bank erosion. The *intensities* of material transport within the

Photo 2.43 There are different ways to protect lands from abrasion. One of them is the construction of lengthwise sea structures. They break waves on their way to the line of cuts and withhold beach deposits. The U.S. Army Corps of Engineers built 55 offshore segmented breakwaters to mitigate the beach erosion problem at Presque Isle State Park (Pennsylvania, United States), which caused the loss of this important recreational site and environmental habitat for wildlife (Photo credit: Ken Winters, U.S. Army Corps of Engineers, 28 October 1992)

coastal zone differ greatly, varying from almost zero to several million cubic metres/year, with an average value of 150,000–600,000 m^3/year (Encyclopaedia ocean-atmosphere 1983).

Beach drift directly influences navigation (making shoals that constitute a threat to shipping). It also creates difficulties for construction and operation of hydraulic structures servicing water transport (ports, navigable canals, piers, moorage walls, bulwarks, docks, slipways, etc.). The problem of material accumulation in navigable canals passing through sandy beaches is of special concern.

The *second factor*, stream-bank erosion, influences harbour installations and other water transport infrastructure located directly on a shore. A striking example of such impact is the Spurn Hd cape in the Humber River estuary, on the eastern coast of England. There, during the period 1674–1786, abrasion destroyed a whole chain of lighthouses one by one. And another tragic example of stream-bank erosion is the demolition in 1360 of the English port of Revenser Odd (Restless landscape 1981).

The effects of abrasion on *recreational activities* also occur by two *means*. *Beach drift* can destroy the valuable portions of the bottom (from the viewpoint of underwater hunting, attractiveness for visitation by free divers, etc.). *Stream-bank erosion* can demolish health resort infrastructure and shorelines. For example, the Victoria Beach area is an important recreational zone for the Nigerian capital of Lagos. As a result of abrasion, 2.5 km^2 of beaches were destroyed there, and erosion also began to threaten a residential area behind it (Goudie and Viles 1997).

A striking example of the effects of abrasion on an *apartment block* is the demolition of a holiday village not far from the city of Bridlington (east coast of England). This village was constructed during the period between two world wars; however, the sea cliff edge approached the houses early in the 1940s. All attempts of owners to protect their property proved to be unsuccessful. After several cottages fell from the cliff to the beach, the local authorities insisted upon demolishing the remaining structures (Restless landscape 1981).

A mechanism of the impacts of abrasion on *motor roads, railroads, pipelines, transmission facilities,* and other infrastructure is the same. The undercutting of bank slopes results in their collapse, which causes damage to nearby facilities. On the whole, the effect of abrasion on human activities is very great. On a *global scale*, damage due to abrasion can be estimated at US$7–8 billion a year (Govorushko 2007a).

The effects of abrasion on human activities are illustrated by Photos 2.41–2.43.

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3 Meteorological Processes

Abstract

Meteorological processes are those processes that take place in the Earth's atmosphere. The lower part of the atmosphere (troposphere), with thicknesses of 8–18 km, is of primary importance. Essentially, the sole energy source for meteorological processes is solar radiation. The existence of climatic zones and formation of different situations that determine weather conditions are caused by an uneven influx of solar energy to the Earth's surface. The nonuniformity of radiation conditions is largely related to the astronomic factors (variations of the Sun's luminosity, variations of the Earth's orbit elements, and other parameters) and local physico-geographical conditions (orography, distribution of land and sea, relief of underlying surfaces, and other conditions).

Keywords

Meteorology • Meteorological processes • Rates • Origins • Human activity • Economic loss • Mortality

All *meteorological processes* may be characterized by certain indices: wind speed and direction, temperature, humidity, barometric pressure, amount of precipitation, and others. The atmospheric conditions at a particular location at a stated time interval are called the *weather*.

Climate is different from weather: It can be characterized as the average range of weather conditions observed in a locality over a long period of time. Therefore, the weather is a particular manifestation of a location's climate. *Climate* depends chiefly on geographic latitude, altitude above sea level, and remoteness from the ocean. The *weather* is determined by the features of incoming air masses and thermal conditions at the Earth's surface – land and water. In general, the climate is permanent, while the weather changes every day.

Meteorological processes have the greatest effects on *air transport*. The *basic meteorological factors* affecting an aircraft during flight are wind, turbulence, hail, lightning, and icing due to ice accumulation on the surface during flight through supercooled clouds.

Horizontal and vertical changes of wind velocity (ascending and descending turbulent streams, squalls, etc.), icing, thunderstorms, and fog at airports are of primary importance. Owing to adverse meteorological conditions, on average, 130 air crashes a year took place in the world during the period 1973–1983 (Myagkov 1995). Adverse meteorological conditions are officially recognized as a cause of 6–20% of air crashes; in addition, they have made a considerable contribution to similar incidents (Astapenko 1986).

According to other data, economic *losses* to airlines due to adverse weather at airports and along air routes

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are 2.3–3.5% of total yearly income (Smith 1978). The *reasons* for these losses are cancellations of flights, increases in flight duration, deviations of routes, transportation of additional fuel, necessary operating repair, and others. To a large extent, meteorological conditions determine the required length of landing strips at airports; the required lengths depend on the type and weight of aircraft, altitude of the airport above sea level, temperature, humidity, and wind velocity. A principal factor determining the aircraft lifting force is air density, which depends on the altitude, temperature, and humidity. The longest take-off roll is needed in summer at high-altitude airports.

Meteorological factors also affect, to a considerable degree, the operating efficiency of *water transport*; many atmospheric phenomena are dangerous to water transport. The major meteorological *factors* that determine the navigational conditions for seagoing craft are wind and conditions caused by the wind at the water surface – roughness, horizontal visibility range, and phenomena that worsen it (fog, precipitation). Sky conditions – cloudiness, sunshine, and visibility of stars and the Moon – also affect navigation on water bodies. Weather conditions that affect navigation safety are also of *economic importance*, affecting fuel consumption, transit time, etc. Weather conditions should be also taken into account when organizing handling operations, especially for cargoes (tea, fruits, timber, etc.) that are sensitive to atmospheric conditions.

Ground traffic is affected by the weather to a lesser extent, but safety is often overestimated, especially when a threat develops. The most important *obstacles* for motor transport are rain, snow, fog, and glaze ice. For example, adverse weather in the United States is a cause of 20% of traffic accidents (1.2 million a year); the average annual death toll reaches about 15% of the total number of victims; that is, 6,000–7,000 people. In 70% of weather-related events, a cause of accidents is rainfall; in 25%, snowfall; and in 4%, fog (Myagkov 1995). Adverse weather conditions often result in financial expenditures. It is estimated that expenses just for protection of roadways against snow and ice amount to US$3 billion a year in the world (Smith 1992). Snowfalls and snowstorms cause difficulties for the operation of railways; however, motor vehicle traffic depends on the weather more than railway traffic does.

Meteorological conditions have a significant impact on *construction operations*. According to data of C. Smith (1978), US$39.7 billion (45%) of the US$88 billion expended for construction in the United States in 1964 was spent for operations related to the weather. Forty-three essential operations performed in the course of the erection of buildings are, to a greater or lesser degree, sensitive to the weather. Depending on the roughness of the weather conditions, related losses range from US$3 billion to US$10 billion a year (Smith 1978). The most significant meteorological *parameters* are rain, wind, low temperatures, and snow, as well as their various combinations.

Meteorological processes are of paramount importance to *agriculture*. The distribution of crops is determined primarily by climate, and their productivity depends, first of all, on weather conditions. Major meteorological *factors* that influence plant development and ageing are air temperature, atmospheric precipitation, and solar radiation.

Meteorological processes influence *sports activities*. In many cases, the weather conditions are the most important and, sometimes, the determining factor. For example, *sailing* and *windsurfing* are impossible under either stormy or calm conditions. For *glider pilots* and *parachutists,* meteorological conditions that do not interfere, at least, with the lights of aircraft are needed. Hard frost or excessive heat, rain or snow, tight fog, strong winds, snowstorms, etc., are able to distort, to a considerable degree, the results of competitions of *skaters, skiers, biathlonists, track-and-field athletes, shooters, tobogganers, orienteers, horseback riders, bicyclists, oarsmen,* and many other sportspeople.

The effects of meteorological factors on the *vital functions* of human beings are widely known. There is the concept of 'meteotropic responses' of the human organism as well as of 'meteolabile' and 'meteostable' persons, who react differently to sudden changes in the weather. People known to react *morbidly* to weather changes include Goethe, Voltaire, Diderot, Heine, Schiller, Byron, Napoléon, Pushkin, Fet, Wagner, Tschaikowsky, Hesse, and Maurois (Kulakov and Kaminsky 2003).

In the first place, the *well-being of a human* depends on air *temperature* and *humidity*. In addition, *wind* creating forced convection can be unfavourable for a human during the cold season and favourable during the frost-free period that follows. Short-wave and Earth-emitted radiations also play a prominent part in human life. Meteotropic exacerbations of cardiovascular and other diseases are related to frontal passages that result in rapid changes of air temperature and pressure.

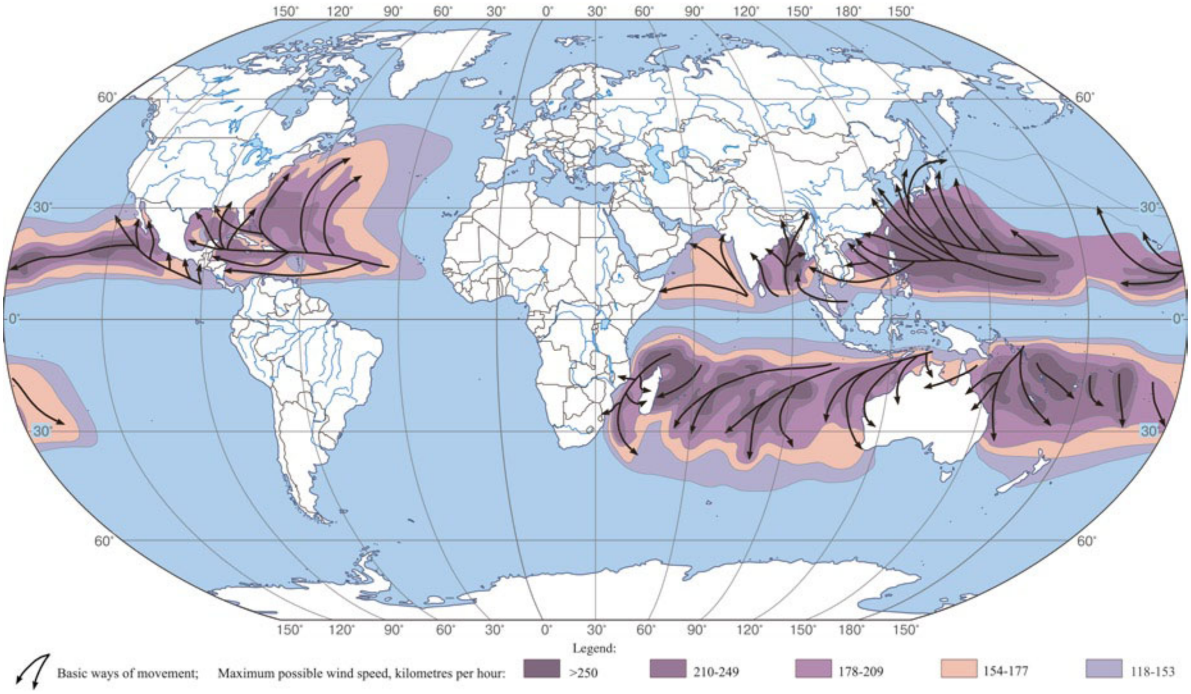

Fig. 3.1 Distribution of tropical cyclones (World map of natural hazards 2006. Reproduced with permission of Munich Re-Geospatial Solutions)

Quick changes in the weather strongly slow down human responses, which results in increases in the number of transport accidents and accidents at work. Often, meteorological effects act through the emotional–psychical sphere. Weather changes have a psychogenic action, lowering the excitability threshold of the vegetative (autonomic) nervous system with respect to the initiating agent. For example, deterioration in the weather can influence the emotional–psychic state of persons suffering from bronchial asthma, causing an increase in the number of asthma attacks (Kulakov and Kaminsky 2003).

In the following sections, basic meteorological processes and phenomena that affect human activities are considered.

3.1 Tropical Cyclones

Tropical cyclones are atmospheric vortices with considerable intensity and relatively small diameter that occur over the oceans in the tropical latitudes. In most cases (87%), tropical cyclones *are born* between latitudes of 5° and 20° in both the northern and southern hemispheres. It is impossible for tropical cyclones to develop within the zone between 5°N and 5°S, because of the absence near the equator of the deflecting force of the Earth's rotation, which is needed for stable circular motion of air (Astapenko 1986). The *northern tropical Pacific Ocean*, where about 30 cyclones are born every year, is most productive. The distribution of tropical cyclones is shown in Fig. 3.1.

Within certain areas, tropical cyclones are given their *own names* (typhoon, hurricane, willy-willy, baguio, cordonazo, etc.). Every year, between 80 and 100 tropical cyclones arise above the Earth's surface; however, only some of them reach destructive force, and few of them make landfall (Babosov 1995). About 15% of the world's population resides in territories exposed to their effects (Smith 1992).

Tropical cyclones usually *occur* in late summer or early autumn, when the water at the ocean surface is the warmest. In winter, they are very *rare,* while in spring, they are practically *absent*. The *ratio* between the numbers of tropical cyclones arising in autumn, summer, and winter is approximately 20:10:1. In the

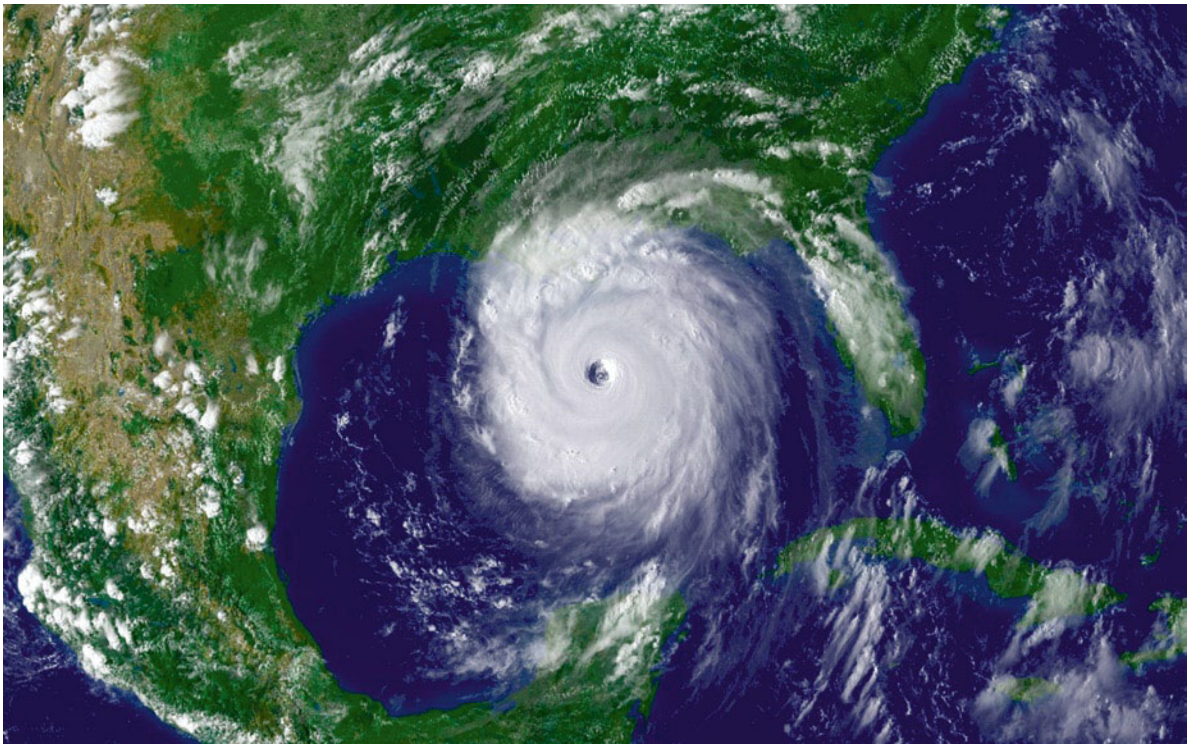

Photo 3.1 The approach of a tropical cyclone is observable by the quick pressure drop and abrupt increase in the wind speed. Then, a heavy shower is observed, usually with a thunderstorm. When the eye of the storm reaches an area, a short calm is suddenly established. After that, the wind increases again, and its direction reverses. The photo is a space image of the tropical cyclone Katrina in the Gulf of Mexico, off the US coast (Photo credit: U.S. National Oceanic and Atmospheric Administration, 28 August 2005)

southern hemisphere, their frequency is three times less than in the northern hemisphere. The *lifetime* of a tropical cyclone is several days to 2–3 weeks.

The major *cause* of the development of tropical cyclones is a powerful ascent of heated, humid air above a large area of the ocean. The annular system of deep convective clouds that is formed moves along a parabolic trajectory to the high latitudes, and there, the wind speed drops gradually. Strong winds and heavy rainfall are characteristic of tropical cyclones. In the centre of the cyclone, called the 'eye' of the storm, the descending air motion causes the weather to be calm and clear.

The *approach of a tropical cyclone* is evident by the quick barometric pressure drop and dramatic growth in the wind speed. In the sky, clouds appear in the following order: from cirrus to cumulonimbus clouds; their density and vertical extent increase gradually. Then, heavy showers begin, accompanied quite often by thunderstorms. When the eye of the storm arrives, a full calm occurs; however, these conditions last only for a short time. After passage of the eye of the storm, the wind sharply intensifies again, but now, it is the rear of the spiral system of winds, and the wind direction is reversed (Weisberg 1980).

The *major characteristics* of tropical cyclones are as follows: overall diameter, 300–400 (rarely up to 800–900) kilometres; 'eye' diameter, 15–30 (sometimes up to 60) kilometres; travel speed, from 20 to 30 to 50 km/h; and maximum wind speed, 300–400 km/h.

The following *basic factors* cause the destructive effects of tropical cyclones: (1) winds having great speeds, affecting the land and causing the storm surge, (2) turbulent (eddy) motion of the air particles, (3) low pressure in the 'eye' of the storm, and (4) abundant showery rains resulting in floods.

Tropical cyclones affect many economic entities and *kinds of human activity*: (1) transport, (2) agriculture, (3) industrial and civil engineering, (4) offshore oil and gas extraction, (5) forestry, and (6) people (Govorushko 2009a). They have the maximum effect

Photo 3.2 One of the main factors that account for the destructive effects of tropical cyclones is strong winds over the sea. They often beget mass shipwrecks, since ships either sink or are thrown into the seashore. The photo shows a fishing boat that was cast ashore by Hurricane Camille, 17 August 1969 (Photo credit: U.S. National Oceanic and Atmospheric Administration, August 1969)

on *sea and air transport*. The influence on the *former* is chiefly related to the wind and sea roughness. In September 1906, a tropical cyclone in the Hong Kong harbour sunk 11 large ships, 22 medium-size vessels, and more than 2,000 junks. During the period 17–23 October 1988, Hurricane Joan destroyed one-third of the fishing fleet of Nicaragua (Davis 1997, vol 2).

The effects of cyclones on *air transport* are related to the thick clouds, which complicate the orientation of flights; turbulent motion of air particles, which causes dynamic effects on the aircraft body; and strong, impetuous winds. Examples of such phenomena are the wreck of a U.S. Navy aircraft with 11 persons on board on 26 September 1955 during Hurricane Janet, and the crash of an aircraft in the state of New Mexico (United States) on 17 September 1988 during Hurricane Gilbert, when the aircraft simply fell to pieces (Myagkov 1995).

An example of *simultaneous effects* on these modes of transport is an event during a typhoon close to the Philippine island of Luzon on 17–18 December 1944. The vessels of the Third Fleet of the U.S. Navy were returning after performing a landing operation. During the typhoon, three vessels sank, 28 others were damaged, and, in addition, 156 aircraft fell into the sea from the decks of aircraft carriers and were lost. The total number of drowned people reached 790 (Babosov 1995).

The effects of tropical cyclones on *agriculture* are related to the strong winds and heavy showers, which result in mechanical damage of leaves and branches, drowning of crops, and knocking off of fruits and nuts. When Hurricane Inez passed the Dominican Republic on 24–29 September 1966, the entire grain yield was lost. Hurricane Gilbert, during 12–19 September 1988, levelled banana plantations in Jamaica; in addition, all of the poultry was killed, and 90% of the crops decayed and were lost. Hurricane Flora, during the period 30 September to 9 October 1963, ruined a quarter of the sugar cane plantations and 90% of the coffee yield in Cuba (Davis 1997, vol 2).

The effects of cyclones on various *industrial and civil structures* are chiefly caused by strong winds and low pressure in the eye, which can result in explosions of buildings due to the difference between the pressure inside the buildings and the atmospheric pressure in the eye. In the course of a typhoon in Tokyo on 30 September 1918, about 200,000 dwellings and a great number of other structures (hospitals, hotels, a brewery) were demolished. A typhoon in Osaka on 21 September 1934 destroyed 87 schools and 3,082 small textile mills (Natural-anthropogenic processes and ecological risk 2004).

The influences of tropical cyclones on *offshore oil and gas extraction* are related to the strong winds and wind-driven waves. As a result of Hurricanes Katrina and Rita in autumn of 2005 in the Gulf of Mexico, 108 oil and gas production platforms were completely ruined, and 53 suffered serious damage. The collapsed platforms accounted for 1.7% of all oil production in the gulf. The effects on *forestry* are expressed as destruction of forests.

Photo 3.3 The impacts of hurricanes on dwellings and industrial structures are caused, in particular, by strong wind. This aerial photo shows the extensive damage on Guam (Honolulu District, Hawaii, United States) caused by Typhoon Pongsona, 8 December 2002 (Photo credit: Andrea Booher, U.S. Army Corps of Engineers)

Tropical cyclones result in vast numbers of *victims*. People perish under destroyed buildings and drown during flooding of cities and towns, shipwrecks, and aviation accidents. Maximum numbers of victims of tropical cyclones are characteristic of India and Bangladesh. Of 20 tropical cyclones with death tolls of more than 500 people occurring in the world in the last 40 years of the twentieth century, 11 events occurred in India, and 4 occurred in Bangladesh (Natural-anthropogenic processes and ecological risk 2004).

The yearly *mortality* related to tropical cyclones is 15,000 people. As for the annual average *economic losses*, we estimated them in 2002 at US$7–8 billion (Govorushko 2003). The maximum losses (US$4.8 billion) were recorded for the southern and south-eastern coasts of the United States (Natural-anthropogenic processes and ecological risk 2004). However, the catastrophic hurricanes Katrina and Rita exceeded these figures in autumn of 2005.

The effects of tropical cyclones on human activities are illustrated by Photos 3.1–3.3.

3.2 Extratropical Cyclones

An *extratropical cyclone* is an atmospheric disturbance with reduced pressure at the centre and vortex motion of the air (anticlockwise in the northern hemisphere and clockwise in the southern hemisphere). The global distribution of extratropical cyclones is shown in Fig. 3.2.

At the beginning of their development, extratropical cyclones have diameters of about 1,000 km, and the diameters later increase to 2,000–3,000 and, sometimes, 4,000 km. They come into being commonly at polar Arctic (Antarctic) atmospheric fronts where cold and warm air masses approach and meet. Extratropical cyclones generally move from *west to east,* but in cases of meridional transformations of the air circulation,

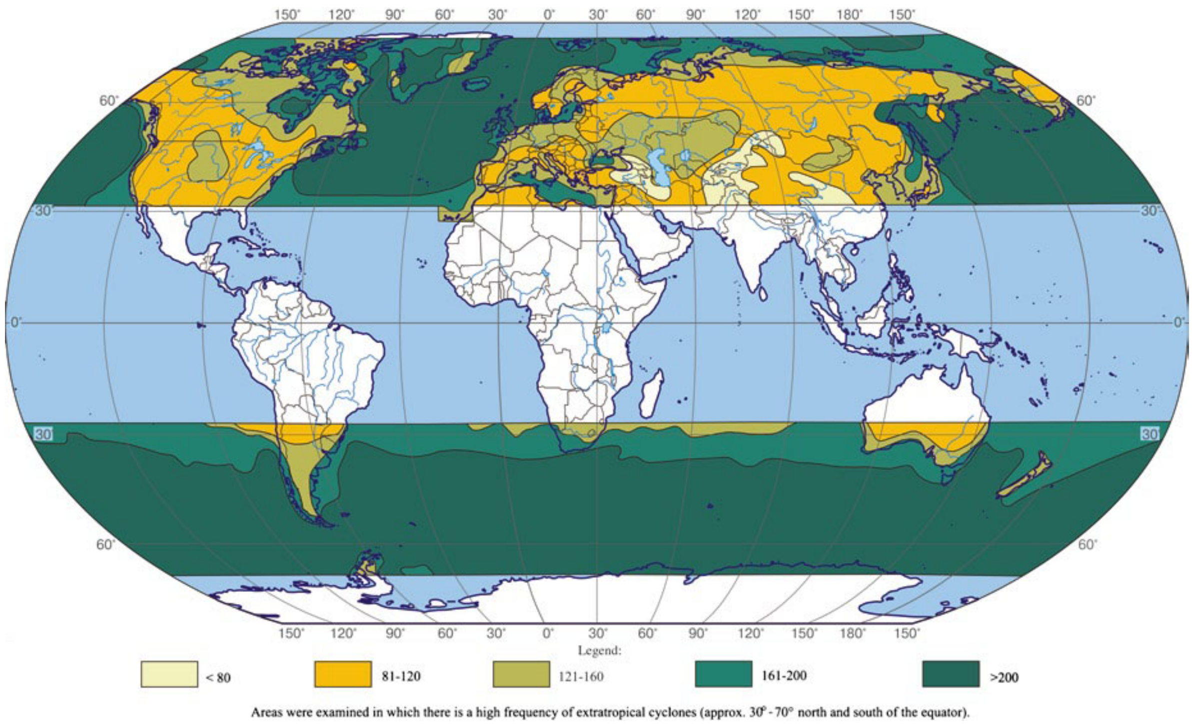

Fig. 3.2 Global distribution of extratropical cyclones (winter storms) (World map of natural hazards 2009. Reproduced with permission of Munich Re-Geospatial Solutions)

their movement to the north and south is possible. The *lifetime* of an extratropical cyclone is several days to 1–2 weeks and more, and their total *yearly numbers* are estimated at several hundred (Geographical encyclopaedic dictionary 1988).

Middle-latitude cyclones are larger than tropical cyclones, and the pressure is higher at the centre. On the other hand, middle-latitude cyclones have less water and weaker winds. During their lifetime, they travel a *path* of up to 10,000 km, including a distance of about 5,000–7,000 km over land, with movement of the system of 30–40 km/h; sometimes, it can reach 100 km/h, or on the contrary, drop to zero. Over the North Atlantic, extratropical cyclones arise all year round and move to Eurasia. In some of these cyclones, the *wind speeds* reach hurricane force on the coast of Western Europe, and the storm intensity lessens in Eastern Europe.

In Western Europe, the *period* with extreme wind strengths is several hours to 3 days (Myagkov 1995). The strongest winds, according to data of A.S. Kurbatova and co-authors (1997), were observed in December 1894 and February 1903, when they reached a value of 70 m/s (250 km/h). Besides the wind intensification, the approach of a cyclone is accompanied by *general deterioration of the weather*: cloudiness, precipitation, thunderstorms, snowstorms, fogs, glaze ice, etc.

In extratropical cyclones, the front and rear parts, as well as the left and right parts, are distinguished according to their motion direction, and the weather conditions in them are different. In the *front* part, continuous stratified cloudiness and widespread precipitation with southerly winds are characteristic. At the *rearward* area of the cyclone, showers are usually observed behind the cold front, the winds are directed to the north and north–west, and breaks in cloudiness and even short-term periods of clearing can occur.

The *left* (more often, the northern) part of an extratropical cyclone is characterized by weather conditions that are intermediate between those in the front and rear parts: the surface winds have east and north-east

Photo 3.4 The effects of extratropical cyclones on sea transport are also related to the strong winds and waves they cause. The photo shows a boat grounded on a dock, St. Martin de Ré fishing harbour (St. Martin de Ré, Ré Island) during a violent storm, Xynthia, that hit France on 28 February 2010 (Photo credit: UNESCO, Lucia Iglesias, 2010)

directions, cloudiness is continuous, and widespread precipitation falls intermittently and gradually changes to scattered showers. The *right* (southern) part of a cyclone is, at first, filled with warm air that is gradually displaced upwards. Weather without heavy precipitation is characteristic; in winter, there is fog or low stratified cloudiness, while in summer, cloudless warm weather with gentle or moderate south-westerly winds is typical (Astapenko 1986).

The effects of extratropical cyclones on human activities are related to the *following factors* (Govorushko 2008): (1) wind, (2) intense snowfalls, (3) long-lasting continuous rains or brief showers, and (4) other adverse weather phenomena (snowstorms, fogs, glaze ice, etc.). The effects of middle-latitude cyclones are similar to those of tropical cyclones. The major difference lies in the fact that they are accompanied by *snowfalls* in winter.

As an example of the influence of extratropical cyclones on *sea transport,* one can cite a storm on 27 November 1703, which sunk 300 vessels and killed 30,000 seamen near the southern coast of England (Davis 1997, vol 2). The effects on *rail transport* are illustrated by the demolition of a rail bridge by a cyclone on 28 December 1879 on the eastern coast of Scotland. During this time, a train was crossing the bridge, and in the resulting accident, 75 persons perished.

During the passage of the winter storm Lothar on 25–27 December 1999, 120 *transmission towers* were toppled in France alone, and as a consequence, more than three million houses lost power. The death toll in France, Germany, and Switzerland reached more than 80 people, and economic losses were US$12 billion.

Extratropical cyclones have pronounced effects on *forestry*. For example, a hurricane in January 1952 levelled about 5% of the coniferous commercial timber in Great Britain (Astapenko 1986). At the same place, in 1987, 15 million trees were uprooted by the wind (Mitchell 2001). During the passage of the winter storm Lothar on 25–27 December 1999 mentioned above, only in the solid wood Pilat (administrative department Loire, France), trees were destroyed over an area of 1,721 ha; that is, 6.4% of its total area. Even after they weaken during their passage over Western Europe, extratropical cyclones do significant damage to forests in Eastern European countries. So, 14.1 million cubic metres of the standing timber in Czechoslovakia and 10.4 million cubic metres of standing timber in Romania were damaged by deadfalls during the period 1959–1964 (Stoiko and Tretyak 1983).

The effects of extratropical cyclones on human activities are illustrated by Photos 3.4 and 3.5.

Photo 3.5 The impacts of extratropical cyclones on forestry are caused by strong winds and heavy snowfalls. The volumes of damaged wood are often measured in millions of cubic metres. The photo shows timber hurled by wind in a fir tree forest in the Ural Mountains (Russia) (Photo credit: V.A. Kantor, Greenpeace, Russia, August 2004)

3.3 Tornadoes

A *tornado* is an atmospheric vortex arising in a thundercloud and stretching to the Earth's surface. *Most often*, they are observed in the United States, where 900 tornadoes are recorded yearly (Smith 1992). The *greatest frequency* of tornadoes in the United States is confined to the so-called *tornado alley* – a zone stretching from Texas through Oklahoma and Kansas and farther to regions of the Midwest. In *other regions* of the globe, the greatest frequency of tornadoes is characteristic of Italy, where with regard to the area occupied, the frequency of tornadoes is comparable with that in the United States, South Africa, south-western and south-eastern Australia, New Zealand, Bangladesh, India (Ganges River valley), Japan, and Argentina (Encyclopaedia ocean-atmosphere 1983). The global distribution of tornadoes is shown in Fig. 3.3.

Tornadoes are initiated by *interactions* of two air layers greatly differing in temperature, moisture content, density, and wind patterns, which result in disturbance of the equilibrium between these layers. Tornadoes do not necessarily stay on the Earth's surface; they can quickly rise above it and go down again – that is, 'jump' over some areas (Weisberg 1980).

A tornado is in the form of a pole between the clouds and the earth, becoming wider upwards and downwards. The air in a tornado rotates *anticlockwise* in the northern hemisphere and *clockwise* in the southern hemisphere. A tornado sucks dust, water, and other things from below it. The major *characteristics* of tornadoes are as follows: diameter, 0.1–1 km; maximum wind speed, 350–400 (up to 720) km/h; average path length, 20–25 km; and centre motion speed, 65–100 km/h.

Every year, about 1,500 tornadoes appear on Earth. Their *lifetimes* are, on average, 10–30 min; however, sometimes they can reach 1 h on the Russian Plain, 5 h in Great Britain, and 7.5 h in the United States (Kurbatova et al. 1997).

Tornadoes often arise in *groups*. For example, in April 1974, 148 tornadoes developed within 2 days over the eastern United States, killing 315 and injuring 6,142 people; the damage was US$600 million (Betten 1985). The most disastrous tornado ever recorded travelled a distance of 325 km through

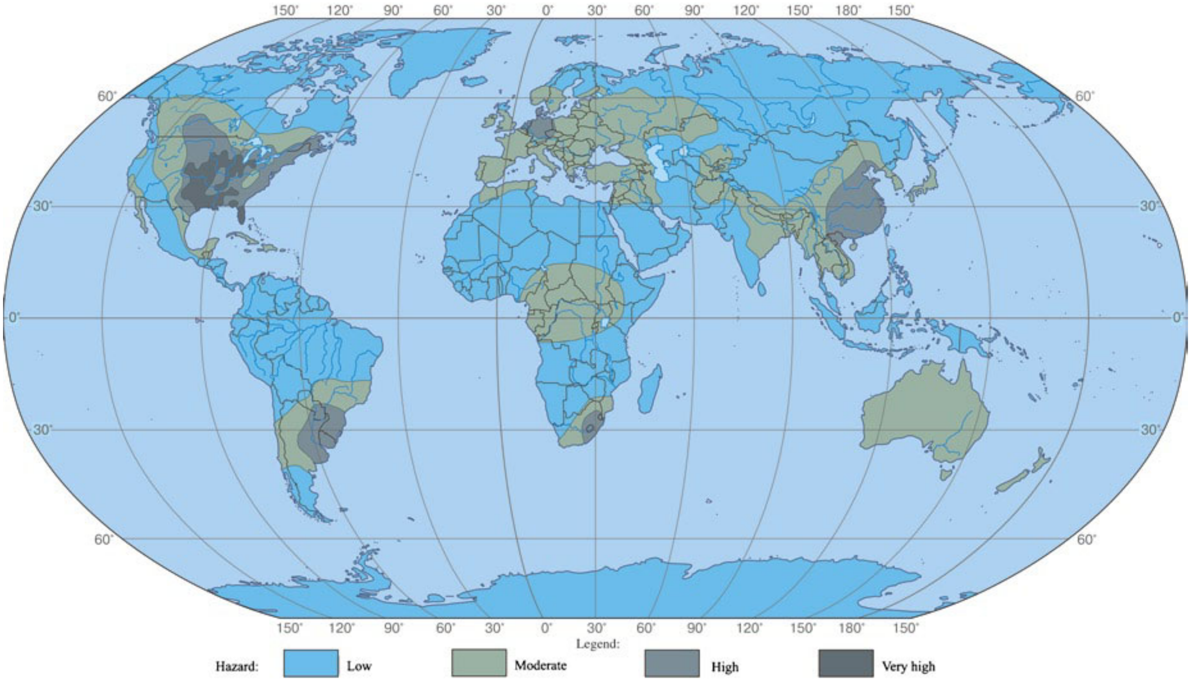

Fig. 3.3 Global distribution of tornadoes (World map of natural hazards 2009. Reproduced with permission of Munich Re-Geospatial Solutions)

Missouri, Illinois, and Indiana (United States) on 18 March 1925; it had an average speed of 27.7 m/s and a width of 0.8–1.6 km. The total area of destruction was 425 km^2, and the death toll was 695 people (Scheidegger 1981).

The damage done by tornadoes is generally related to the following *reasons*: (1) lateral pressure and blows, (2) vortical damage, (3) explosive ruptures, and (4) combined destructive forces.

Because the *funnel of a tornado* consists of a compacted mass of air, water, fragments (debris), dust, and dirt travelling at high velocities, the impact force can be very large and able to destroy any house. The *lateral pressure* and impacts (blows) overturn buildings, displace them over spitting distances (upon the earth or air), and break walls, but they never turn the structures into brash. The most well-known example of such destruction is the overturning of several four-storey brick buildings of a spinning mill during the Montville tornado on 19 August 1845 in France (Nalivkin 1984).

Vortical damage is a widespread effect of tornadoes on structures. The destruction rates depend on the vortex motion rate and are conditionally subdivided into three categories. According to witnesses, this damage can appear as *follows*: (1) a building is broken to pieces, (2) a house is removed before one's eyes, and (3) a house disappears with lightning speed (Nalivkin 1984). The lifting force of a tornado may be very strong. The *heaviest object* known to have been lifted by a tornado is the iron pendant bridge across the Big Blue River near Irving, Kansas (United States). The bridge may have weighed as much as 108 t (Nalivkin 1984).

Explosive ruptures result from the sharply decreased pressure in the tornado cavity. When this cavity touches closed objects (houses, chests, canisters, cans, car tyres), air flowing from a cavity to the funnel blows up. For example, during a tornado on 2 April 1957, a modest wooden house in Dallas, Texas (United States), was smashed to smithereens by such an explosion (Nalivkin 1984).

Damage caused by the *combined destructive forces* of a tornado is caused by the joint action of several processes, for example, a combination of a side impact with vortical destruction or a simultaneous explosion. Most of the destruction caused by tornadoes is due to combined forces.

Tornadoes influence many *kinds of human activity*. Objects damaged most often include the following (Govorushko 2005): (1) residential and industrial

Photo 3.6 The funnel of a tornado consists of a solid mass of air, debris, water, dust, and filth. When a funnel is moving at high speeds, the strength of a strike against motionless obstacles can be very high. The plank that pierced the dwelling's wall was impacted by by-blow. The tornado occurred on 8 May 2003 and caused US$300 million in property damage (Photo credit: University Corporation for Atmospheric Research, United States)

Photo 3.7 The devastation shown in Omaha, Nebraska (United States), triggered by a tornado on 23 March 1913, is typical of combined devastation. Though whirl-type destruction prevailed, several buildings were subjected to by-blow and blast-type destruction. The calamity killed 154 and made more than 3,000 homeless (Photo credit: U.S. National Oceanic and Atmospheric Administration)

buildings, (2) all kinds of transport, (3) bridges, (4) forests, (5) crops, and (6) water supply systems.

The demolition of *residential buildings* occurs most frequently, and in the course of a tornado passage, it can be massive. During a tornado on 9 June 1953, about 4,000 buildings were destroyed in Worcester, Massachusetts (United States), while a tornado on 23 March 1913 destroyed 600 houses and seriously damaged 1,100 buildings in Omaha, Nebraska (United States) (Davis 1997, vol 2).

The destruction of *industrial buildings*, by virtue of their greater structural strength, is not so typical; however, such occurrences are not exactly rare. In addition to the above-mentioned four-storey brick buildings of the spinning mill in France, similar examples include the demolition of a steelworks (employed 500 workers) in Wheatland, Pennsylvania (United States); the demolition of a 10-metre radio tower and a mill in Atlantic City (United States), during a tornado on 31 May 1985, across Pennsylvania; and the destruction of a knitting factory in Gainesville, Georgia (United States) on 1 June 1903 (Davis 1997, vol 2).

Of all kinds of transportation, *motor transport* is affected by tornadoes the most. *Cars* are overturned due to side impacts, they are subjected to vortical forces and explosive ruptures, and they are damaged owing to bombardment by fragments. Effects on *rail transport* are also widespread. In 1913, the side impact of a tornado in Illinois (United States) derailed and practically destroyed 20 cars of a freight train.

Other examples of *side impacts* are the overturning of a *tram* with passengers on 23 March 1913 in Omaha, Nebraska (United States), and the overturning of 11 steam *locomotives* in the marshalling yard at Murphysboro, Illinois (United States) on 18 March 1925 (Davis 1997, vol 2). An example of the power of the *swirling motion* of a tornado occurred on 27 May 1931 in Minnesota (United States); a *railway car* with 117 passengers was carried over a distance of 24 m (Weisberg 1980).

An example of the effects of tornadoes on *air transport* is the crash of a B-36 bomber with 15 crewmen on board. The incident happened on 25 May 1955, when the aircraft flew over the city of Sterling (Texas, United States) The tornado was not touching the Earth's surface at the time. Another example of effects on aviation is the crash of an F-28 passenger aircraft making the Rotterdam–Hamburg flight on 6 October 1981. During the flight at a height of 900 m, the aircraft encountered the tornado. In all likelihood, due to the side impact, the right wing separated. As a consequence, all 17 persons aboard were killed (http://aviation-safety.net/database/1981/811006–0.htm). When tornadoes pass over airports, damage to parked aircraft is typical.

Effects on *water transport* are also known. For example, a tornado overturned two big steamers chock-full of passengers and 60 flat-bottomed boats on the Mississippi River (United States) on 7 May 1840 (Davis 1997, vol 2).

Influences of tornadoes on *bridges* are fairly typical. In the case of the Irving tornado on 30 May 1879, a reason for the destruction of a bridge was the swirling motion. The iron bridge, 75 m long, was bent and curled, and at the same time, the bridge was compacted into a package 1.5–2 m in diameter (Merkulov 1989). When a tornado passed across the city of Monticello, Indiana (United States), on 3 April 1974, a railway bridge was also destroyed, but here, the lateral impacts played a key role. Four elements weighing 115 t each were thrown off concrete pillars over a distance of 16 m (Ionina and Kubeev 2000).

A certain negative influence is also exerted by tornadoes on *forestry*, which becomes apparent in windfalls. As a consequence, wood decays and access to harvesting areas is complicated. The numbers of fallen trees are commonly much smaller than in the case of hurricanes; nevertheless, they may be fairly large. For example, a tornado passing in early May 1952, across a big stand near the city of Göttingen (Germany), toppled 56,000 trees (Ionina and Kubeev 2000). Tornadoes also influence agriculture, and this effect is evident in soil aeolation.

To some extent, tornadoes influence *water supplies*. The effect is caused by ascending air and low pressure in the funnel of the tornado. Quite a number of cases are known when tornadoes completely sucked the water out of deep wells. In the literature, many events are described when tornadoes crossing rivers completely absorbed the water. Such a phenomenon was observed during a tornado in 1904 on the Moskva River (Russia), on one of the tributaries of the Mississippi River (United States) on 18 June 1939, and in the lower reaches of the Rhine River.

In 1858 for example, in crossing the Rhine River, a tornado formed a trench in the river with a length of 600 m, a width of 80 m, and a depth of 7 m. The total weight of the raised water reached 336,000 t. Events of water absorption out of *lakes* also have been recorded. In this respect, the Lorain tornado crossing Lake Erie (United States), 40 km wide, and the Rostov tornado, covering several kilometres over Lake Nero (Russia), are most well known. Each of them absorbed some tens of millions of tons of water (Nalivkin 1984).

On the whole, tornadoes have pronounced effects on human activities. On a global scale, they cause an estimated 120 *deaths* and *losses* of US$600–700 million every year (Govorushko 2005).

The effects of tornadoes on human activities are illustrated by Photos 3.6–3.9.

Photo 3.8 This photo shows airplanes at the U.S. Air Force base in Oklahoma that were damaged by a tornado on 20 March 1948. This tornado was the first one to be reported approaching by radio. The planes were damaged by side pressure and numerous blows (Photo credit: U.S. National Oceanic and Atmospheric Administration, 25 March 1948)

Photo 3.9 Tornadoes have impacts on forestry through blowing about timber; the path of a tornado is shown by the broken trees. Blow-downs destroy woods and make it impossible to log high-quality timber in an area, as well as to reach the lumber sites. The photo shows an incense loblolly pine (*Pinus taeda* L.) woodland annihilated by a tornado (Photo credit: Ronald F. Billings, Texas Forestry Service, Bugwood.org)

3.4 Thunderstorms

A *thunderstorm* is an atmospheric phenomenon in which, in thick cumulonimbus clouds and between clouds and the Earth's surface, multiple electrical discharges – lightning – arise, which are accompanied by thunder. The thunderstorm is a very *widespread* phenomenon: On Earth, 1,800 thunderstorms are taking place at any given time, and 117 lightning events occur every second. The *number* of thunderstorms on the Earth is about 16 million annually (Tikhonov et al. 1997). Average numbers of thunderstorms (days/year) are shown in Fig. 3.4.

The numbers of thunderstorms over the land and sea are roughly equal; that is, their frequency over land is much higher than that over water. Thunderstorms are *characteristic* of regions with hot climates, where temperatures and humidity are high all the year round. The *record* for the number of thunderstorms at a particular location (242 thunderstorms a year) is noted near the capital of Uganda (city of Kampala) (Clouds and cloudy atmosphere 1989).

The *diameters of thunderstorms* range from 0.5 to 10 km, with an average value of 1 km (Weisberg 1980). In the course of their passage, thunderstorms affect an area of 500–2,500 km^2 (Encyclopaedia ocean–atmosphere 1983).

The impacts of thunderstorms can be subdivided into the following *categories*: (1) electrical discharges (lightning), (2) noise nuisance (thunder), (3) turbulence, (4) short-term wind intensification (squalls), (5) hail, (6) showers, and (7) supercooled moisture contributing to icing of aircraft.

Lightning is a giant spark discharge of atmospheric electricity. Generally, the lower part of a cloud has a negative charge, while the top part is positively charged; however, clouds can bear a charge of the same sign. Lightning can be a discharge between a charged cloud and earth, between oppositely charged clouds, or between parts of clouds (Gomzikov 1995).

The *danger of lightning bolts* is attributed to the *following*: (1) high voltage (hundreds of millions of volts), (2) great current strength (tens of thousands of amperes), and (3) very high temperatures (up to 25,000–30,000°C). Lightning can be subdivided into

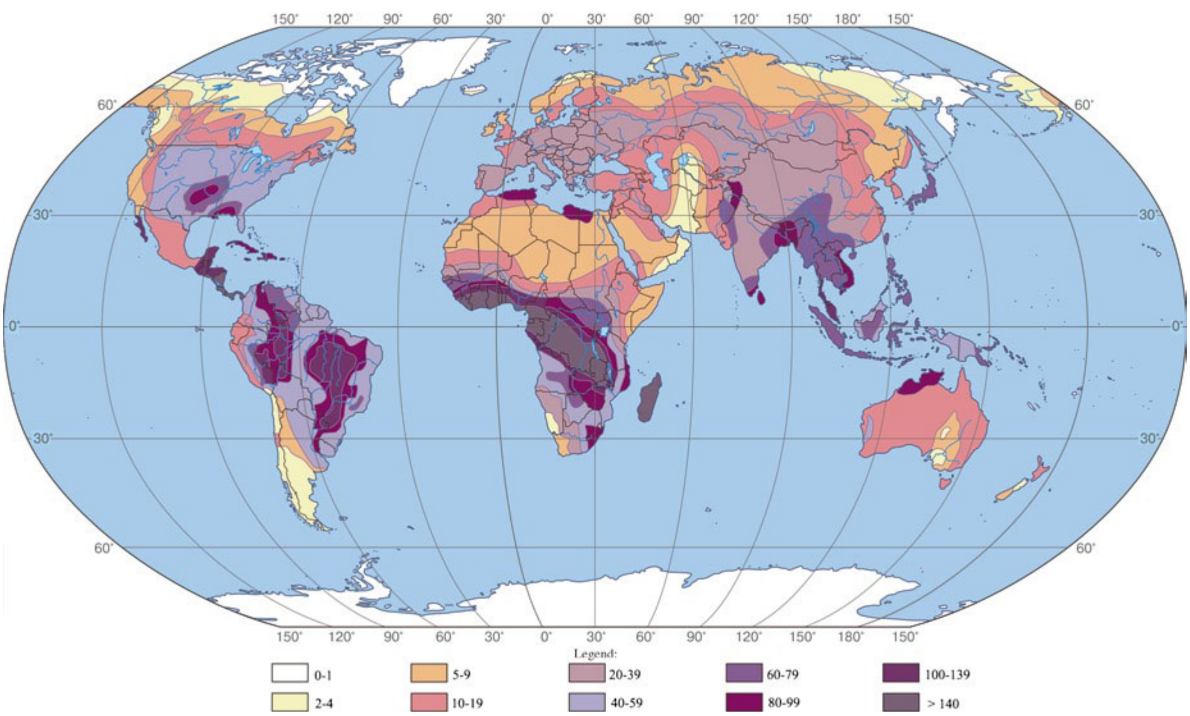

Fig. 3.4 Average number of thunderstorms (days/year) (Reproduced with permission of U.S. National Lightning Safety Institute)

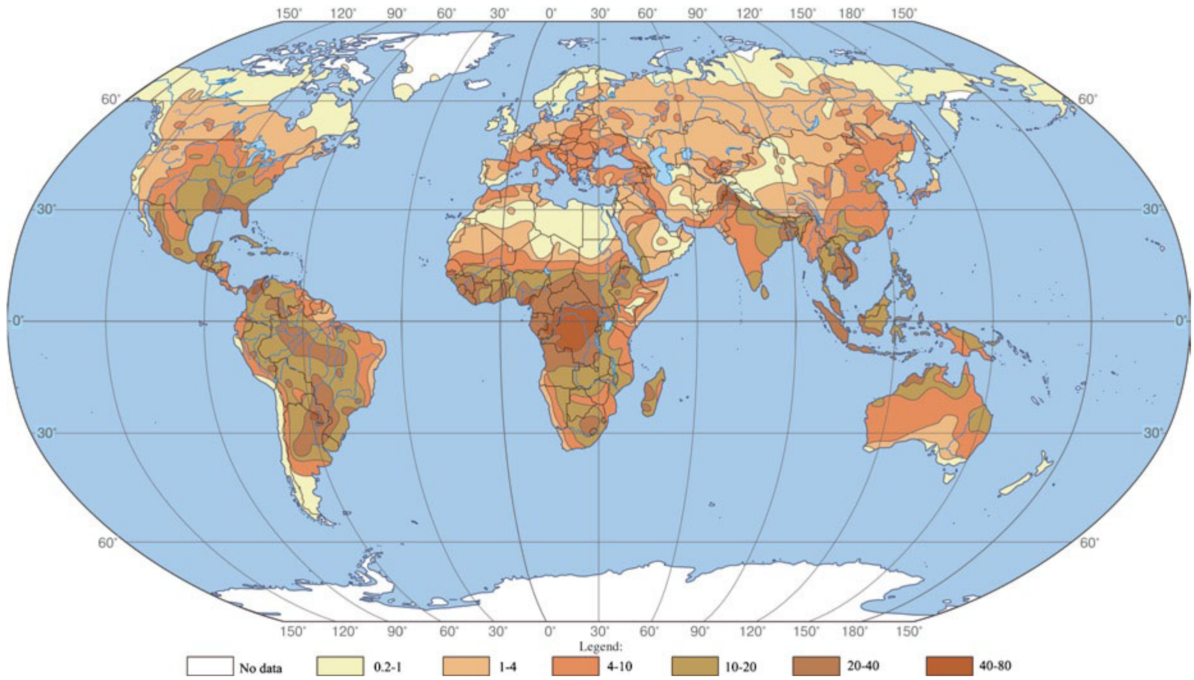

Fig. 3.5 Global frequency of lightning strokes/km² and year (World map of natural hazards 2009. Reproduced with permission of Munich Re-Geospatial Solutions)

the following *kinds* (Tikhonov et al. 1997): (1) streak, (2) ball, (3) beaded, and (4) flat.

Streak lightning is the most dominant phenomenon during thunderstorms. It represents a long spark having the shape of a broken or zigzagging, brightly glowing line. Streak lightning is generally several kilometres long. A streak with a length of 190 km (118 miles) is considered to be a record (Cerveny et al. 2007). About 78% of all lightning is recorded between 30°S and 30°N (Mareev and Trakhtengerts 2007).

In cases of small, isolated thunderstorms, about 3 flares/min are observed, but cases are known when, in the course of heavy thunderstorms, more than 100 flares/min have been recorded (Encyclopaedia ocean-atmosphere 1983). The most strikes per year were observed in the Democratic Republic of the Congo: more than 70/km² (http://en.wikipedia.org/wiki/List_of_weather_records). The global frequency of lightning strokes is shown in Fig. 3.5.

Ball lightning occurs much more rarely than streak lightning; it is observed in the course of heavy thunderstorms. It resembles a luminous ball of 3–20 cm in diameter. The traverse speed of ball lightning is small; it may even be motionless for several seconds. The lifetime ranges from several seconds to a minute. The temperature of ball lightning is 527–1027°C; it may enter structures through relatively small cracks; that is, it is plastic (flexible). Ball lightning disappears completely or seems to vanish into thin air or to explode (Astapenko 1986). Other kinds of lightning seldom occur.

Thunder is a sound wave produced by lightning. During the lightning stroke, there is quick and extreme heating and, consequently, air expansion in the channel of the lightning. A wave that creates a sound effect – thunder – is generated. *Turbulence* is a deviation of the air-flow rate from the steady-state regular mode.

The effects related to strong winds, showers, hail, and supercooled drops in thunderclouds are considered in the appropriate sections.

Lightning during thunderstorms is the *major factor influencing* human activities. The strikes are quite often a direct or indirect cause of loss of life. They result in the mechanical failure of buildings and other structures and cause fires and explosions. Mechanical failure results from an instantaneous conversion of water into high-pressure steam. A primary impact represents a direct lightning strike. Secondary effects

Photo 3.10 Ball lightning is a luminous ball, 3–20 cm in diameter, that moves slowly. The image shows the trajectory of its movement. The photo was taken during a daytime thunderstorm that took place near Nagano, Japan (Photo credit: S. Kamogawa, 25 July 1987)

include the *following* (Gomzikov 1995): (1) electrostatic induction, (2) electromagnetic induction, and (3) importation of high electric potentials into buildings and other structures.

Thunderstorms strongly influence human activities, resulting in high mortality and complicating many *activities*: (1) air transport, (2) transmission facilities, (3) industrial and civil engineering, (4) forestry, (5) livestock farming, (6) recreation and sports, and (7) radio and telephone communications (Govorushko 2009b).

The chief reason for *loss of life* during thunderstorms is electrical shock in cases of direct strikes. The question of how many people survive lightning strikes is debatable. There are mortality estimates of 30% (Cherington 1995), 20% (Andrews 1995), and 10% (Cooper et al. 2001).

In most cases (91%), a lightning strike results in loss of only one life, while in 8% of such accidents, two persons are killed. As to percentage of populations killed by lightning, Zimbabwe, where 200 persons out of ten million perish every year due to lightning strikes, is a leader. Values close to this estimate are characteristic of countries adjacent to Zimbabwe. Mortality figures include 51 people in Kenya (Vovchenko 1985), 55 people in France, and ten people for every ten million in the United States (Myagkov 1995). On a global scale, *annual mortality* from thunderstorms is estimated at 500 people (Thunderstorms 1981, V. 1).

The effects of thunderstorms on *air transport* are determined by lightning and turbulence. As a rule, the destructive effects of *lightning strikes* on aircraft are limited to small fused spots on the exterior aircraft skin at the points of cable inlets and outlets, melting of antennae, and small breaches in the forward fuselage or tail assembly (Encyclopaedia ocean-atmosphere 1983). Sometimes, lightning strikes cause damage to navigational facilities and electronic equipment, ignition of fuel vapours in fuel tanks, and other effects.

A list of recorded aviation accidents caused by lightning strikes includes seven incidents, with a death toll of 307 people. Lightning also complicates *space travel*. For example, on 14 June 1969, lightning struck the Apollo 12 spacecraft twice and damaged it seriously. Three astronauts were aboard the spacecraft (Betten 1985).

The operation of *air transport* is, to a considerable extent, complicated by *turbulence,* which may result in disruption of aircraft control, destruction of separate construction elements, and even aviation accidents. The *microbursts* representing the descending mass of heavy, cold air released by the 'mature' thunderstorm cloud – that is, a cloud that has ceased its development and has burst into a heavy shower – are particularly dangerous. Microbursts are no more than 4 km in diameter. Their danger consists, first of all, in their suddenness (they are hidden from meteorological radar) and, second, in their high power. According to various data, the

Photo 3.11 Thunderbolts striking dwellings and industrial structures is a typical phenomenon. Thunderbolts induce fires and explosions, and mechanical destruction of buildings, as well as several secondary impacts, such as electrostatic and magnitude induction, and development of high electric potentials within buildings. This wall in the ground floor of a house was destroyed by lightning that generated explosive vapourization of grounded steel/ferroconcrete reinforcements. (Photo credit: U.S. National Lightning Safety Institute)

descending *velocity* may range from 112 (Weisberg 1980) to 270 km/h (Forces of nature 1998).

Such descending currents have been the cause of several aviation *accidents*. On 24 June 1975, a Boeing 727 aircraft making a New Orleans–New York flight was coming in to land at the New York John F. Kennedy International Airport. The aircraft was confronted with a windfall having a velocity of 7 m/s (25.2 km/h) at a height of 60 m. The aircraft undershot the runway, killing 113 people (Betten 1985).

Horizontal gusts also pose serious danger for aviation. During a flight from Houston to Dallas on 3 May 1968, an aircraft entered a heavy thunderstorm. The aircrew was permitted to come down and change course. On a right-hand turn, a sharp side gust caused a right roll of 90° and a drop in inclination of 40°. When the crew attempted to come out of the non-standard position, the structural load exceeded the estimated limits of the aircraft. At a height of 2,025 m, part of the right wing broke loose, causing the aircraft to crash (http://aviation-safety.net/database/record.php?id=1980503–0).

Lightning has a pronounced impact on the operation of *transmission lines*. Numerous accidents have been caused by lightning strikes to transformers, which result in fires and fusing of wires (Betten 1985).

The impact of thunderstorms on *industrial and civil engineering* is mainly related to lightning strikes. Tall buildings are most vulnerable. For example, lightning struck the 380-m Empire State Building in New York City 68 times over 3 years (Tikhonov et al. 1997). Lightning regularly hits church belfries, and for 33 years of the eighteenth century, they killed 103 bell-ringers in Germany alone (Forces of nature 1998). Lightning strikes often result in *fires*. For example, about 20,000 structural fires are caused by them every year in the United States alone. In Kenya, 110 houses are burned down every year as a result of fires caused by lightning strikes (Vovchenko 1985).

Fires caused by lightning strikes do substantial damage to *forestry*. Sometimes, they are on a wide scale. On 12 July 1940, lightning strikes caused 335 fires in the forests of Montana and Idaho (United States) (Smith 1978). Every year, they lead to 9,000 forest fires on US territory (Weisberg 1980). All over the world, lightning causes about 50,000 forest fires a year (Spurr and Barnes 1984).

Photo 3.12 Lightning often strikes objects that stand alone; for instance, trees. Various kinds of trees have different susceptibility to thunderbolts, depending on the dimensions of the tree and the roughness of its bark. Tall trees with rough bark are the most susceptible to thunderbolts. Trees die because the water within them instantly turns into vapour when they are struck by lightning. That makes a trunk internally explode and splinter. The photo shows a lightning-struck tree on a golf course in Iowa (United States) (Photo credit: Linda Haugen, USDA Forest Service, Bugwood.org)

The impact of thunderstorms on *livestock farming* is largely related to lightning strikes. For example, a thunderstorm early in July 1959, around the Shar-Planina (south part of the former Yugoslavia), caught a herd of sheep in one of the upland pastures. The lightning struck within the centre of a cluster of animals frightened by the thunder and hail. As a result, about 500 sheep were killed (Vovchenko 1985). Once, 2,000 sheep were killed by a lightning strike in Ethiopia (Olkhovatov 2008).

Thunderstorms also have some effects on *sports and recreational activities*. Apart from the complications for sporting events due to strong winds and rainfall, high numbers of lightning strikes cause difficulties.

Thunderstorms, to a large extent, create difficulties for *telephone and radio communication*. Lightning is a natural source of low-frequency modes in the atmosphere. Within the range of 1–10 kHz, they result in the generation of atmospherics (radio signals), creating a characteristic whistling noise in receivers (Curran et al. 1997).

According to data of the National Oceanic and Atmospheric Administration (United States), *global financial losses* related to thunderstorms reached, on average, US$2 billion a year during the period 1950–2002.

The effects of thunderstorms on human activities are illustrated by Photos 3.10–3.15.

Photo 3.13 This photo illustrates the effects of thunderstorms on space activities. During a powerful electrical storm over the Kennedy Space Center, Florida (United States), lightning strikes the space shuttle *Challenger* before the launch of STS-8 (Photo credit: U.S. National Aeronautics and Space Administration, 30 August 1983)

Photo 3.14 People and animals die from the impact of the electric current during thunderstorms if struck by direct thunderbolts. The photo shows cows killed by lightning (Photo credit: U.S. National Lightning Safety Institute)

Photo 3.15 Turbulence is a very important factor in the impacts of thunderstorms on human activities. It is a sharp change in airflow speed and direction from the usual regime. Aircraft that are landing or taking off are in the most danger. This photo shows vertical microbursts at the Denver International Airport, Colorado (United States). Forced by turbulence, a plane can either be lifted up and miss the runway or touch down before the runway, whether it is an ascending or a descending gust (Photo credit: University Corporation for Atmospheric Research, United States)

3.5 Blizzards

A blizzard occurs when snow is transported by strong winds over the ground surface. Most often, blizzards happen in Antarctica (100–200 days a year), Russia, Canada (first of all, on the Atlantic coast and in Ontario), the northern United States, Nordic countries, Mongolia, and northern Kazakhstan.

Three types of blizzards have been identified (Atlas of snow and ice resources of the world 1997, vol II, Book 2): (1) upper drifting snow (snowfall accompanied by strong winds before the landfall of atmospheric snowflakes), (2) low-level snow drifting (movement along the Earth surface of both newly fallen snow and previously fallen snowflakes), and (3) overall drifting snow (combination of upper drifting snow and blowing snow). The overwhelming majority of blizzards are blowing snow or overall drifting snow.

A blizzard may be *saturated* – that is, transporting the maximum possible amount of snow at a given wind speed – and *unsaturated*, when the snow mass transported by the wind is less than the maximum possible. In the case of blowing snow, the snow-and-wind stream is infrequently saturated. The overall drifting snow blizzards are, as a rule, fully saturated.

In the case of blowing snow, *three types of sections* have been identified (Voitkovsky 1999): (1) snow removal section, within which there is snow blowing, (2) drift-snow transport section, with a relative balance between snow being blown and deposited, and (3) snow accumulation section. The distance over which the total saturation of the flow (stream) takes place is called the *blizzard acceleration distance*.

Separated snowflakes can not be carried for miles and miles. They either become stable in the snow cover or decay when they collide with other snowflakes or evaporate. On the whole, the *snow transfer range* – that is, the distance at which the snow-and-wind stream is entirely renewed – increases with increasing wind speed, reduction of air temperature, and growth of air humidity and sizes of snow particles. This range is 1–2 km in the European territory of Russia, 2–3 km in

Photo 3.16 The intensity of a blizzard depends on the wind flow speed and turbulence, intensity of snowfall, shapes and sizes of snow particles, nature of the snow surface, and air temperature and humidity. The volume of snow transported by low-level snow drifting is proportional to the third degree of the wind speed; that is, when the wind speed increases 4 times, the volume of the snow transported increases 64 times. Low-level snow drifting in the state of South Dakota (United States) is shown (Photo credit: University Corporation for Atmospheric Research, United States)

western Siberia, 5–10 km in the Arctic, and 10–20 km or more in Antarctica (Kotlyakov 1997).

The *volume of snow* that is carried in the course of low-level snow drifting is proportional to the *third* power of the wind speed, while in the case of upper drifting snow, it is directly proportional (Myagkov 1995).

Blizzards result in loss of life and affect many *kinds of human activity*: (1) industrial and civil engineering, (2) livestock farming, (3) crop production, (4) transport, (5) recreation, (6) transmission lines, (7) radio communication, (8) mineral resource industry, and (9) forestry.

Loss of life during blizzards is typical. The pressure of the snow stream smothers, there is sharp visibility deterioration, and people are dumped on, which, combined with the low temperatures, results in death from hypothermia. Among the most well-known cases are the loss of 1,000 lives during 1–29 February 1956 in Western Europe; 400 lives on 11–14 March 1888 in the eastern United States and in 1988 in New York; 300 lives in November 1850 in the Kaluzhskaya province (Russia); 239 lives in August 1996 in the Himalayas, India; and 237 lives in 1960 (eastern United States) (Kovalevsky 1986; Myagkov 1995; Forces of nature 1998; http://www.oars.utk.edu).

The influence of blizzards on *industrial* and *civil engineering* is seen as a reduction in the safety and accessibility of buildings. The accumulation of snow on building roofs creates excess loads and, as a result, the collapse of buildings. For example, more than 250 cases of damage to buildings due to excessive snow loads were recorded in Canada during 1959–1971 (Kotlyakov 1994). The sliding of snow from oblique roofs can cause trauma and loss of life, while snowdrifts near buildings often complicate access to them.

Photo 3.17 Blizzards redistribute snow by blowing it away from some sites and accumulating it at others. The photo shows telegraph poles near Jamestown, North Dakota (United States), impacted by a heavy blizzard (Photo credit: Bill Koch, U.S. National Oceanic and Atmospheric Administration, 9 March 1966)

Blizzards have marked effects on *grassland farming*. Fairly often, the dynamic impact of the snow-and-wind stream, visibility deterioration, and sweeping up with snow give rise to *mass mortality* of animals. During a violent blizzard in the winter of 1827–1828, more than one million sheep, 280,500 horses, and 73,450 head of cattle were killed in the Saratov province (Russia) (Borisenkov and Pasetsky 1988).

Blizzards have various effects on *crop production.* The snow redistribution causes a deep winter frost penetration and lack of moisture in snowless places and over-wetting and late thawing where snow accumulates. In regions with thin snow cover, the winter crops projecting above the smooth ice-covered surface are often damaged by loose ice particles.

The impact of blizzards on transport is considerable. Their effects are most pronounced with respect to *motor transport*. The major influencing factor is snowdrifts, which often slow down traffic. Roads on mountain passes and road sections that are in the wind shadow and in topographic lows are *snowbound* to a great extent. Another factor is *abrupt visibility deterioration.*

The effects on *rail transport* are similar in many respects. In the course of a storm in 1941, railway transport in the northern United States was completely paralyzed, and trains moved by way of a detour through the Canadian prairies (Snow 1986). In January 1952, a fast train was caught for 4 days on the Donner Pass in the northern Sierra Nevada (United States) (Kotlyakov 1994).

Blizzards have a variety of impacts on *air transport. Snowdrifts* block landing strips. During a blizzard in 1969, the Montreal airport was shut down due to snow accumulation (Snow 1986). During blizzards, especially in warm weather, a great quantity of ice can be formed on the wings and other surfaces of aircraft. If this ice is not cleared before take-off, then *changes in flight characteristics* can cause a plane to crash. For example, an aircraft taking off at the Washington, DC, airport on 13 January 1982 could not go fast enough owing to considerable ice formation, and it hurtled against a bridge crossing the Potomac River. Seventy-four of the 79 persons aboard were killed (Betten 1985).

Blizzards have two main *types* of influence on *recreational activities.* On the one hand, blizzards *restrict activities during winter holidays* (riding snow scooters, skiing, skating, etc.). On the other hand, drifting snow results in an *increase in the thickness of snow cover* on slopes with alpine skiing trails.

The effects on *transmission lines* are chiefly related to the *dynamic impact* of the snow-and-wind stream and deterioration of the *electrical insulating properties* of air. In March 1973, a part of the Saint Lawrence River valley (North America) had no electric power for a week as a result of a snowstorm, and a month later, a storm destroyed a transmission line at Red Deer-Edmonton, Alberta, Canada (Snow 1986).

Photo 3.18 The impacts of blizzards on cattle breeding, mainly pastured animals, are quite strong. The photo shows a herd of bulls that were killed by a blizzard near Brookings, South Dakota (United States). Timely warning would have helped avoid this outcome (Photo credit: U.S. National Oceanic and Atmospheric Administration, March 1966)

Photo 3.19 The blizzard of January 1977 had wind speeds of up to 137 km/h and generated snowdrifts 7.6 m high in Buffalo, New York (United States). The calamity killed 29 and caused US$250 million in property damage. The photo shows Red Cross employees rescuing people in the suburbs of Buffalo. More than 5,000 cars were abandoned on the roads (Photo credit: American Red Cross, February 1977)

Blizzards influence *radio communications* similarly. When snowflakes break up, their snow-drifting electrification results in radio interference in the snow-and-wind stream (Glaciological encyclopaedia 1984). The impact on the *mineral resource industry* is related to complications in the operation of strip mines owing to snow accumulation.

The effect on *forestry* is expressed as mechanical damage to trees, especially conifers. During a severe snowstorm, an evergreen tree, 15 m high with a crown

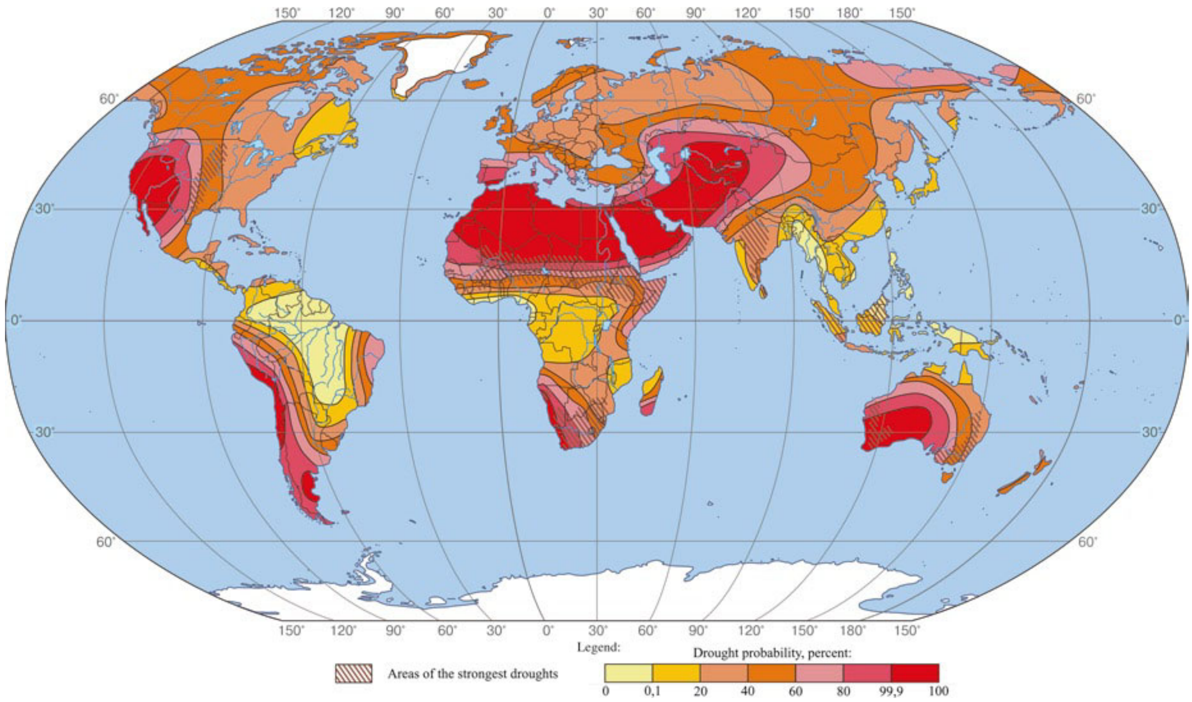

Fig. 3.6 Drought probability, percent (Resources and environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of Sciences)

6 m in diameter, can be covered with ice and snow having a mass of 4.5 ton (Snow 1986).

The effects of blizzards on human activities are illustrated by Photos 3.16–3.19.

3.6 Droughts

Droughts are prolonged periods with low amounts of atmospheric precipitation or the absence of precipitation accompanied by increased temperatures and reduced humidity of air and soil. It is estimated that 40–45% of the continents on Earth falls within stably dry and arid regions; more than a third of the Earth's population resides in these regions (Myagkov 1995). Drought probability is shown in Fig. 3.6.

Droughts are sometimes called the '*creeping danger*', because they develop slowly, often within months, and last for a long time; very severe droughts develop over a period of years. It is usually difficult to identify where and when a drought starts, and in certain cases, it is over before we realize it has occurred. Naturally, the *ideas of a drought* differ strongly between different geographical zones. For example, in *Great Britain* a drought means a period of 15 days running and more with average daily precipitation of less than 0.25 mm. On the other hand, a drought in *Libya* is only acknowledged after a 2-year absence of rain (Smith 1992).

Because people adapt their activities to *expected precipitation*, a drought is more exactly an unexpected decrease in the amount of precipitation. An amount of precipitation of 200 mm a year may be acceptable for a farmer-sheep breeder within the semiarid zone, but this amount turns out to be disastrous drought for farmers who grow wheat and are accustomed to an average annual precipitation of 500 mm.

Droughts have pronounced effects on society, causing considerable mortality and affecting many *kinds of human activity*: (1) crop production, (2) livestock farming, (3) waterpower engineering, (4) water transport, (5) industrial and domestic water supplies, (6) forestry, (7) fishing, and (8) recreation.

The question of *mortality* from droughts is fairly complex. The major cause of loss of life during droughts is hunger. In this respect, differences in the influence of droughts on developed and developing

Photo 3.20 Droughts greatly affect communal and industrial water supplies. This lake in Colorado (United States) dried up after several droughty summers (Photo credit: Carlye Calvin, University Corporation for Atmospheric Research, United States)

countries are greatest as compared with other disasters. At present, people rarely die from droughts in the developed countries, whereas mortality in the developing countries may be very high.

Among the droughts that have caused the *greatest numbers of victims* are the drought of 1920–1921 in the territory of the former USSR, when five million lives were lost; the drought in 1959–1961 in North China, in which about 30 million people died; the loss of two million lives in north-eastern Brazil in 1877 (Smith 1992); the death of more than one million residents of India in 1965–1967; and the loss of 250,000 lives in the Sudan-Sahel zone of Africa in 1968–1974 (Babayev 1983). On a global scale, *mortality* from droughts is estimated at 65,000 people a year (Govorushko 2007).

The impact of droughts on *crop production* consists mainly in the fact that the long absence of rainfall, in combination with a high potential evaporation, results in dehydration of the root-inhabited soil layer. These conditions cause a disturbance in the plants' water supply and abrupt decreases in their productivity. Reductions in crop yields due to drought are very high. For example, about 2.6 million tons of wheat and 2.9 million tons of corn are lost every year in the United States (Betten 1985). In 1988, which was one of the most drought-afflicted years in the century, the reduction in crop production reached 31% in the United States (Riebsame 1991).

The *major factor* influencing *livestock farming* is reduction in pasture performance owing to dehydration of the root-inhabited soil layer. *Other causes* include a lack of water for cattle and increases in predator attacks. Droughts result in reductions in livestock head due to natural mortality and forced slaughter of animals. *In addition*, disruptions in the reproductive cycle (insemination delay and incomplete pregnancy) and animals' weight reduction are also related to droughts. The drought of 1972–1973 in the Sudan-Sahel zone of Africa resulted in the loss of about 80% of the cattle (Repinskaya 2002).

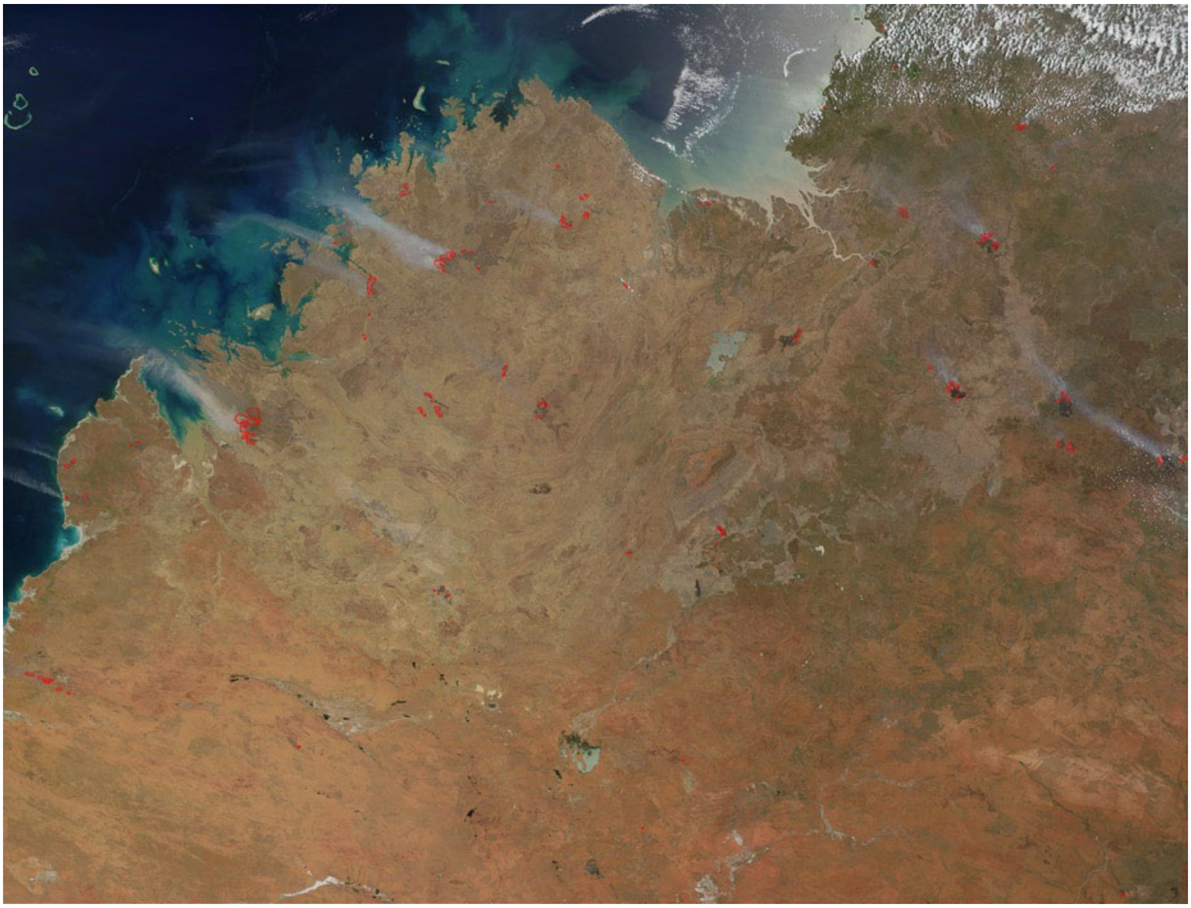

Photo 3.21 Drought is a culprit in most fires. This space image shows innumerable fires in Western Australia induced by dry thunderstorms during a protracted spring drought (Photo credit: U.S. National Aeronautics and Space Administration, 26 October 2001)

The effects on *waterpower engineering* are related to the reduction in river flow. A decrease in the usable water causes reductions in *power generation*. For example, in the course of a drought in India in the summer of 1987, many hydropower plants decreased their output sharply or completely stopped generating electricity (Myagkov 1995). Effects on *water transport* are similar. The decrease in run-off reduces the amount of water in rivers and lakes and complicates (and sometimes stops) *navigation*.

The impact of droughts on *domestic* and *industrial water supplies* is very high. A lowering of the groundwater level dries up wells, while a decrease in the surface water flow results in problems with the supply to water-retaining structures and outages of public waterworks systems. In India, 250 million people experienced shortages of drinking water due to the drought of 1987. Shortages of water for domestic water supplies were also noted in 1990 in the countries of the Mediterranean subtropical region (Repinskaya 2002).

The *major factor* affecting *forestry* is overall decreases in humidity, which increase the likelihood of fires. The *other factors* include a decline in the health of forests due to dehydration of the root-inhabited soil layer, invasions by destructive insects, and spreading of forest diseases. During a drought in 1982–1983, more than 2,000 forest fires arose in Australia, which destroyed hundreds of thousands of hectares of forests (Myagkov 1995).

The effect of droughts on *fishing* is chiefly related to decreases in run-off volume. Rivers become shallow, causing an activation of spawning grounds, and the water temperature increases result in reduced dissolved oxygen content and, thereby, marked worsening of habitability conditions and mass mortality of young fish.

The influence on *recreational activities* is mainly determined by deterioration of the visual appeal of landscapes due to fires, dust in the air due to wind erosion, unpleasantness of withered vegetation, and other factors. For example, fires destroyed 850,000 ha of forests (50% of the territory) in the Yellowstone National Park (Wyoming, United States) during a drought in 1988 (Smith 1992).

The *financial damage* caused by droughts is great. In relative terms, Tanzania, Kenya, and Ethiopia *suffer the most* from droughts. For example, losses in Tanzania due to droughts, on average, are about 10% of primary production a year, which corresponds to 4% of its gross national product (Sytnik et al. 1987). In absolute figures, the economic losses are greatest for developed countries that are producers of crops – the United States, Canada, and Australia – and major developing countries: China and India, for example.

In the United States, for example, the drought of 1980 resulted in the loss of US$19 billion (Sazonov 1991), losses from the drought of 1988 reached US$39 billion (Riebsame 1991), and damage related to the drought of 1998 in the central regions was estimated at US$40 billion (Natural-anthropogenic processes and ecological risk 2004). On a global scale, the average *annual economic loss* is estimated by us at US$10 billion (Govorushko 2007).

The effects of droughts on human activities are illustrated by Photos 3.20 and 3.21.

3.7 Atmospheric Precipitation

Atmospheric precipitation is water in the liquid droplet (rain, drizzle) and solid (snow, sleet, hail) state falling from clouds or settling directly from the air onto the Earth's surface (dew, hoar frost, white frost) as a result of the condensation of water vapour present in the air.

These phenomena occur on a huge scale, as on the Earth, there are no places where precipitation never occurs. The average annual distribution of precipitation in the world is presented in Fig. 3.7.

On the *planet as a whole*, 577,000 km^3 of precipitation falls every year; that is, the average layer height is 1,130 mm. Of this total amount, 458,000 km^3 occurs over *oceans* (average layer height is 1,270 mm), and 119,000 km^3 occurs over the *land*, with an average water layer height of 800 mm. Thus, the precipitation over oceans amounts to 79% of total precipitation, although the oceans occupy only 71% of the Earth's surface area, while 21% of total precipitation falls on land (Khromov and Petrosyants 2001). Only 11% of precipitation is formed by way of evaporation from the Earth's land surface. The remaining 89% is formed by evaporation over oceans (Heinrich and Hergt 2003).

Precipitation *distribution* is very irregular. Nearly half of the total amount falls within the zone *between 20°N and 20°S*. Only 4% of precipitation falls in the *polar zones* (Khromov and Petrosyants 2001). The irregularity of rainfall is revealed not only in space but also in time. For example, one shower in Al Wajh (Saudi Arabia) on 31 May 1984 provided 122 mm of rainfall, which was more than the precipitation for the preceding 10 years (Clouds and cloudy atmosphere 1989).

The *most significant factors* determining rainfall *distribution* are frequency of passage of moist marine air masses and frequency of humid air rise to considerable heights. As for the inter-annual variability of precipitation, it, in relative terms, is the largest for the driest regions – deserts and polar regions – where the minimal amount of precipitation is less than 50 mm and, in so-called wet years, it can exceed 400 mm. The absolute variability is greatest for the most humid tropical and equatorial areas.

Most of the precipitation that impacts human activities falls from *clouds*. These are rain, snow, hail, drizzle, small hail, snow grains, and snow with rain or sleet. Some kinds of precipitation may form from the *air without clouds*: dew, hoar frost, rime, and ice crystals.

The significant index is *precipitation rate,* which measures the depth of precipitation falling on horizontal ground in the water equivalent; it is measured in millimetres per hour. In most regions of the world, the rate of precipitation in the form of *snow* is at least one order of magnitude (i.e. ten times) less than the *rainfall* rate (Rogers 1979).

The amount of precipitation that falls at a location is determined by both *zonal* (distribution of cloudiness and temperatures) and *azonal* (distribution of land and sea, orography) factors. Of fundamental importance for precipitation are *mountain ridges*. For example, 1,730 mm of precipitation falls on the Atlantic coast of Norway (Bergen), while in Oslo (behind the ridge), only 560 mm falls (Khromov 1983). The difference is much more on the island of Oahu, Hawaii, where

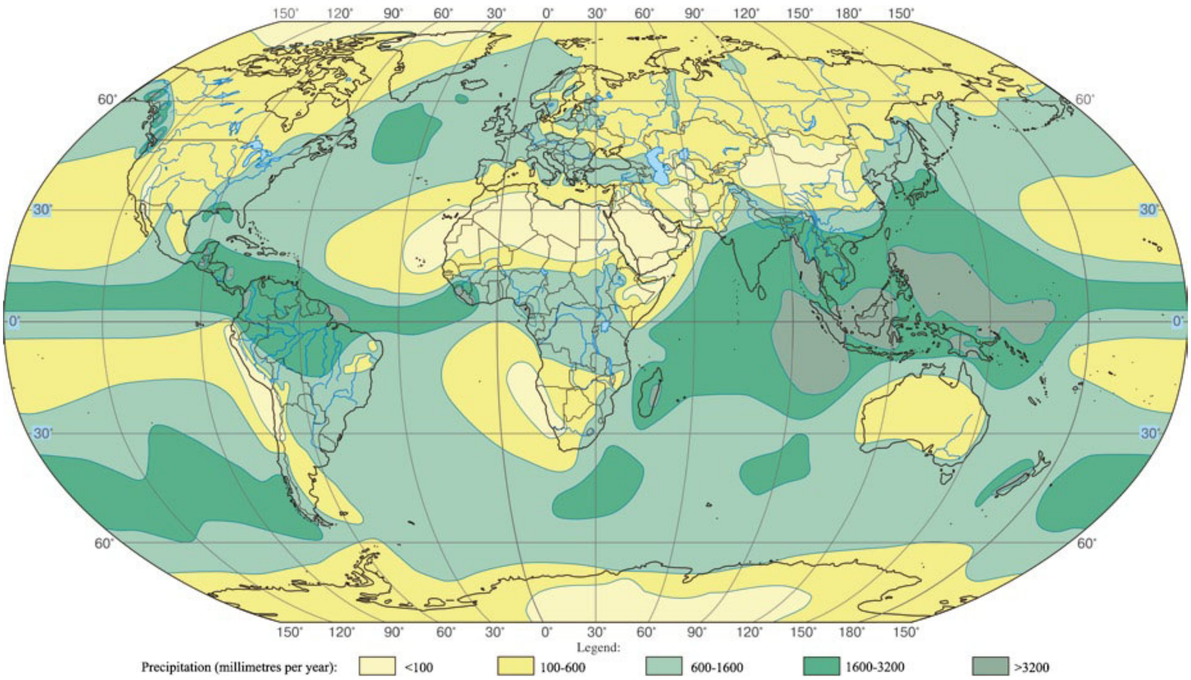

Fig. 3.7 Annual precipitation (Resources and environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of Sciences)

500 mm of precipitation falls, on average, on the upwind slope, while only 25 mm – that is, 20 times less – falls on the downwind slope (Astapenko 1986). *Major kinds* of atmospheric precipitation that are of importance for vital human activities are rain, snow, and hail (Sects. 3.7.1–3.7.3).

3.7.1 Rain

Rain is liquid precipitation falling from clouds in the form of drops 0.5 mm and more in diameter. Rain is the most common kind of liquid precipitation. It falls in all regions of the world except Antarctica.

The *most rainy localities* in the world include the area around Cherrapunji (India) as well as tropical zones of both the northern and southern hemispheres. The *rates* of individual rains can be quite large. The *world's record* was established by a shower passing Barst, Guadeloupe, on 24 November 1970, when the rate reached 38 mm (1.5 in.) per minute. The most precipitation to fall in a *single day* (24-h period) is 1,870 mm (73.62 in.) near Cilaos, Réunion Island, in the Indian Ocean, on 15–16 March 1952 (Reference book of necessary knowledge 1994).

Rain falls from clouds that have lost their stability and are unable to hold the water drops of which they consist in suspension (Astapenko 1986). *Three types* of rain have been identified (Khromov and Petrosyants 2001): (1) continuous, (2) showery, and (3) drizzling.

Continuous rain has the following *characteristics*: (1) large size of the territory in question (hundreds of thousands of square kilometres), (2) rather uniform distribution, (3) significant duration (many hours), and (4) moderate rates. In an area covered by continuous rain, the amounts of precipitation are similar throughout the affected regions. Continuous rain provides most of the precipitation within the *middle latitudes*.

Showery rains are produced by cumulonimbus clouds. They differ from continuous rains in their high rates and short duration. Generally, showery rains *start*

Photo 3.22 In many areas of the world, rain is the main source of moisture for plants. Steady rains are the most propitious ones, since soils easily absorb moisture thanks to uniformity of precipitation. Downpours are far less welcome due to their brevity and greater intensity. This photo shows agricultural lands beaten by a shower in California (United States) (Photo credit: Michael Collier)

suddenly and *cease suddenly*. The average area affected by one showery rain reaches about 20 km^2. The rates of showery rains are characterized by strong variability over the affected area. In the course of one rain, the amount of precipitation falling at distances of 1–2 km apart can differ by 50 mm. Showery rains are the major kind of precipitation in the *tropical* and *equatorial latitudes*.

Drizzling rains do not provide noticeable amounts of moisture. Relatively intense and abundant drizzling rains are observed only in mountains (Khromov and Petrosyants 2001).

Clouds consist of enormous numbers of small water drops. For the initiation of rain, it is necessary that these drops increase considerably in size. The growth of drops is mainly caused by *coagulation* (they merge in the course of colliding). When large drops reach critical sizes and become too heavy to be supported by the ascending motion of air, they begin to fall. *Differences* in the sizes of drops cause them to fall at different rates, and, therefore, they collide more easily. For example, a drop with a diameter of 0.5 mm falls at a rate of 2.06 m/s, while a drop with a diameter of 5 mm falls at a rate of 9.09 m/s (Rogers 1979).

Rain affects many economic entities and *kinds of human activity*: (1) crop production, (2) livestock farming, (3) transport, (4) waterpower engineering, (5) recreation, and (6) civil and industrial engineering.

Along with snow, rain is a major source of moisture for *crop production*. Continuous rains are the most favourable, because the moisture is absorbed by the soil. Heavy rains create difficulties for farm operations because they result in flattening of crops and grasses. During harvesting, prolonged rains cause grains in windrows to germinate, while when plants are flowering, they degrade pollination conditions (Chirkov 1988).

The impacts on *livestock farming* are felt through excessive or insufficient moistening as well as through the duration of rainfall. Excessive moisture creates difficulties for pasturage of cattle, while a lack of moisture adversely affects the productivity of grasses and fodder crops. The duration of rainfall is of importance,

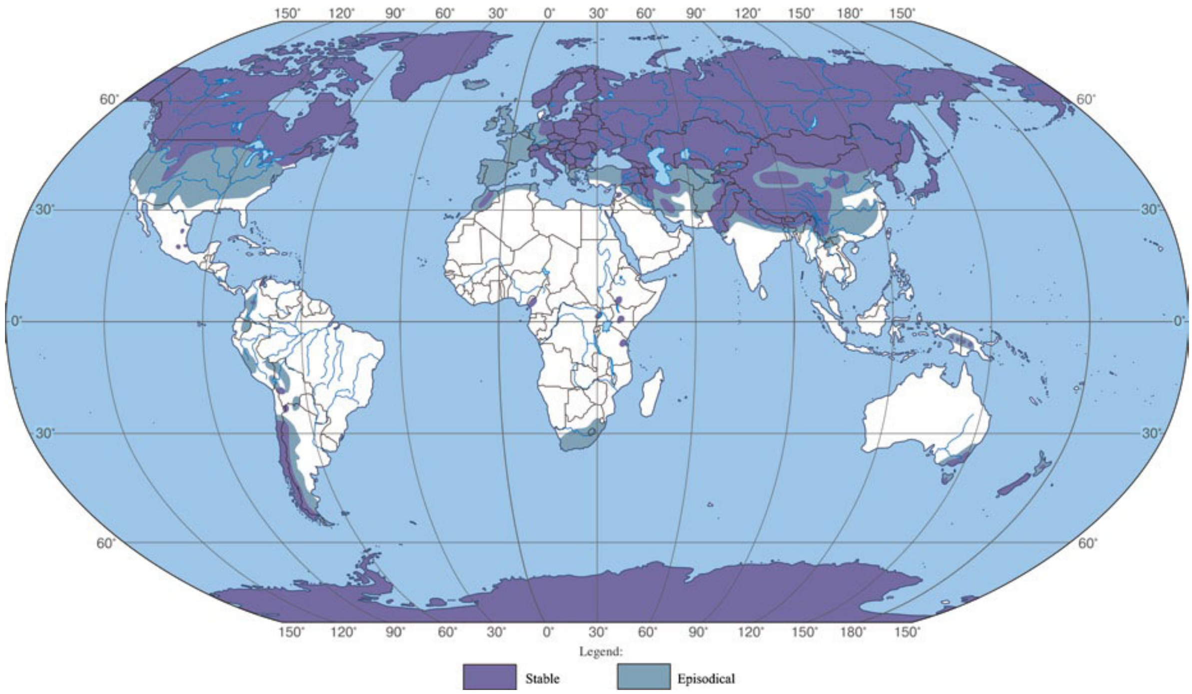

Fig. 3.8 Distribution of snow cover (Resources and environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of Sciences)

for example, for bee-keeping. Prolonged rains during the period of flowering of melliferous plants (e.g. linden) result in sharp decreases in honey production.

Rain also affects *motor transport,* related to visibility deterioration and wet surface conditions. As a result of traffic hindrances and increases in stopping distances, there are numerous road accidents, including collisions of transport vehicles, turnover accidents, and other mishaps. In the United States alone, about 5,000 people are killed in road accidents due to rains every year; rains are a factor in 70% of all accidents caused by bad weather (Myagkov 1995).

The effects of rain on *water and rail transport* are, to a great extent, related to visibility deterioration, while for *air transport*, increases in the slipperiness of runways cause problems.

Rain is an important component of the water balance, which is significant for many kinds of activity requiring large water expenditures (*waterpower engineering, irrigation, water-retaining commercial production, water supplies, aquaculture,* etc.). Rains often cause difficulties for outdoor *recreational activities.* Rain is also one of the most important meteorological parameters influencing *construction operations*.

The effects of rain on human activities are illustrated by Photo 3.22.

3.7.2 Snow

Snow is solid atmospheric precipitation that falls in the form of snowflakes from clouds. Stable snow cover is characteristic of regions with average temperatures of 0°C and lower for the coldest month, while unstable snow cover and rare snowfalls are possible where average temperatures are +10–12°C for the coldest month. Nearly two-thirds of the land area of Earth can have snow cover, and on a fourth of the land, snow cover is present for at least 4 months a year (Myagkov 1995).

The *distribution* of snow cover on the Earth is illustrated in Fig. 3.8. The *maximum annual snow amount* fell during the period 19 February 1971 to 18 February 1972, near Paradise, Mt. Rainier (Washington, United States), and reached 31,102 mm (Reference book of necessary knowledge 1994). Besides the amount of snowfall, the *essential parameters* are the number of days with snow cover and the dates of its first appearance and last occurrence.

The *formation* of snow in the atmosphere is largely related to the availability of supercooled water and ambient temperatures. At about −5°C, *crystallization centres* present in the atmosphere form minute ice crystals having the shape of hexagonal plates. As the ice crystals increase in size and become more complex, they turn into snowflakes. The *diameters* of snowflakes range from fractions of a millimetre to some centimetres, and the *rates* that they fall vary from 0.1 to 2 m/s (the average rate is 1 m/s) (Glaciological encyclopaedia 1984).

Snow influences many objects and *kinds of human activity*: (1) crop production, (2) livestock farming, (3) transport, (4) industrial and civil engineering, (5) forestry, (6) recreational activities, (7) transmission lines, (8) power engineering, and (9) water supplies.

The effects of snow on *crop production* can be *positive* and *negative*, depending mainly on the amount of precipitation and when the snow falls. The *basic factors* determining the effect are the heat-insulating properties of snow, its moisture content, its ability to wash different substances out of the atmosphere, snow loads, and so on.

Basic characteristics of snow cover are the high *albedo* (90–95% for fresh snow and 30–35% for polluted, melting snow) and *low thermal conductivity*, which is directly proportional to the snow density. At an average density of 0.2–0.3 g/cm^3, the heat conductivity coefficient of snow is approximately ten times lower than that for soil (Chirkov 1988). The *heat-insulating properties* of snow are the determining factor for winter agriculture, because the snow protects the shoots from winter-killing; the effects on the root systems of perennial herbs and fruit and berry crops are analogous. However, over-abundant snowfalls on relatively warm ground result in *asphyxiation* of crops.

When soil temperatures at a depth of 3 cm are lower than −15°C, which, to a large extent, is a consequence of too little snow, *winter-killing* of winter crops takes place. For example, due to the absence of snow in south-eastern Europe in 1972 and 1974, the plantings of winter wheat were not protected against frosts. As a result of damage to the crops, prices of wheat increased all over the world (Snow 1986).

The role of snow in *providing plants with moisture* is extremely important. In 28 countries having a total irrigated land area of 185 million hectares, snow is the major source of irrigation water (Kotlyakov 1994). At the same time, too much snow can result in great increases in soil moisture and run-off, and stagnation of meltwater in the fields can cause *damping-off* of plants. Historical chronicles suggest that, every 10–20 years, hunger in Russia has been caused by damping-off of plants near Moscow, Pskov, and Novgorod (Sazonov 1991).

Not infrequently, increased winter precipitation results in *delays in the sowing* of crops. Delayed sowing is especially unfavourable for regions with short growing seasons. In a number of cases, negative effects on plants are caused by *snow loads*. Fruit trees and plantings are destroyed under the weight of the heavy snow. This phenomenon is especially dangerous in regions where snowfalls are rare and heavy. For example, in February 1956, a snowfall in central Italy lasted 6 days, causing the destruction of 80% of the citrus and olive trees (Forces of nature 1998). Early snowfalls seriously complicate *harvests*.

The influence of snow on *livestock farming* is mainly expressed as difficulties in the livestock gaining access to fodder. For example, in the winter of 1948–1949, snowfall in the western United States proved to be twice as much as normal. As a result of this, winter pasturage of animals proved to be impossible. In spite of the fact that many tons of concentrated foods and hay were airdropped and delivered on the snowbound roads, 25% of the cattle were killed (Snow 1986).

Snow is of great importance in the operation of different modes of transport, especially *motor transport*. For example, a snow layer 5–10 cm deep in the United States creates significant difficulties for traffic on roads, while a layer 20–30 cm deep essentially paralyzes it (Myagkov 1995). The impacts on *rail transport* include delays of *train* operation and problems in the remote closing of railway switches. The visibility deterioration related to snowfalls creates problems in the operation of *all modes of transport* except for pipelines.

A negative effect on *industrial* and *civil engineering* is, to a great extent, caused by *snow loads*, and the cardinal problem is in the failure of roofs. For example, in January 1978, Switzerland and northern Italy experienced extremely heavy snowfalls. In some regions, the snowfalls were two to three times greater than the

Photo 3.23 Negative influences of snow on industrial and residential systems are, to a larger extent, caused by snow loads. In this case, the major problem is related to the roof collapse. Snow accumulation also creates difficulties in approaching the houses. This photo was taken during the winter of 2007–2008 in Ottawa, Canada (Photo credit: John Talbot, 9 March 2008)

Photo 3.24 Snow seriously complicates the operation and upkeep of motor vehicles and transportations systems. Snow decreases visibility, while accumulation on the road surfaces increase slipperiness and can make them impassable. The photo shows a road during a snowstorm in Oslo, Norway (Photo credit: Ilan Kelman (http://www.ilankelman.org))

Photo 3.25 Heavy snowfalls not only deprive livestock of food but also make it impossible to move. Heavy snowfalls of August 1992 in the eastern part of South Island, New Zealand, entrapped numerous herds of sheep. The photo shows a farmer trying to move sheep to safety (Photo credit: Tony Allan, Bendrose Station, Twizel, New Zealand)

maximum values taken into consideration in designing buildings. Specific snow pressure reached 200 kg/m^2. As a result, the roofs of many buildings crashed down under the weight of the heavy snow (Astapenko 1986).

The effects of snow on *forestry* are also mainly related to snow loads. For example, in April 1976, as a result of a fall of moist snow (depths reached 75 cm) in the Black Hills (South Dakota, United States), destruction of coniferous forests was recorded over an area of 250,000 ha. Accumulating on the tops of trees, the snow broke tree trunks up to 10–15 cm in diameter (Snow 1986).

Snow is of prime importance for some kinds of *recreational activity*. For example, Alpine skiing, tobogganing, and cross-country skiing are impossible without it. Snow is widely used to create snow-ice sculptures. At the same time, snow often creates difficulties for this activity. The presence of snow cover increases illumination outdoors to a considerable degree. Strong light reflection and scattering in snow-capped mountains can result in temporary blindness among Alpinists, downhill skiers, and others engaging in winter sports (Khromov and Petrosyants 2001).

The influence of snow on *transmission lines* is related to snow loads, which often cause wires to break and towers to fall. For example, 60 cm of sleet fell in the south-west part of the Saskatchewan province (Canada) during a 12-hour period in May 1974. Accumulations on the wires reached about 15 cm, causing 113 km of transmission lines to go offline (Snow 1986). The influence on *power engineering* is related to the fact that masses of snow accumulated in winter supply the water necessary, first of all, for power engineering. The significance of snow for *water supplies* is related to its important role as a component of the water balance.

The influences of snow on human activities are illustrated by Photos 3.23–3.25.

3.7.3 Hail

Hail is atmospheric precipitation that falls in the form of spherical particles of compact ice. Hail usually falls during thunderstorms; however, *not every thunderstorm* is accompanied by hail. For example, hail is observed in the middle latitudes eight to ten times less frequently than thunderstorms (Astapenko 1986).

A leader in the frequency of hail is Armenia, where the average annual number of days with hail reaches 20 in some areas (Myagkov 1995). A considerable number of hail hits is also recorded in some areas of the United States (up to six times a year), France, Georgia, mountainous areas of the central Asiatic countries (three to four times), and foothills of the Carpathians (Astapenko 1986). The global distribution of hail storms is shown in Fig. 3.9.

Hail usually accumulates to several centimetres deep, although, in 1965, hail near the town of Kislovodsk (Russia) coated the ground with a layer 75 cm deep (Astapenko 1986). The hail-fall *duration* is several minutes to half an hour, but most often, 5–10 min. About 500–1,000 hailstones fall in 1 min on 1 m^2; their *densities* are 0.5–0.9 g/cm^3, and the *rates of fall* reach tens of metres per second.

An important characteristic is also the *sizes* of hailstones. Generally, they do not exceed 1 cm in diameter; however, many cases of much larger hailstones are known. The *largest hailstone* ever officially measured was 17.8 cm (7.0 in.) in diameter and 47.6 cm (18.75 in.) in circumference, in Aurora, Nebraska, on

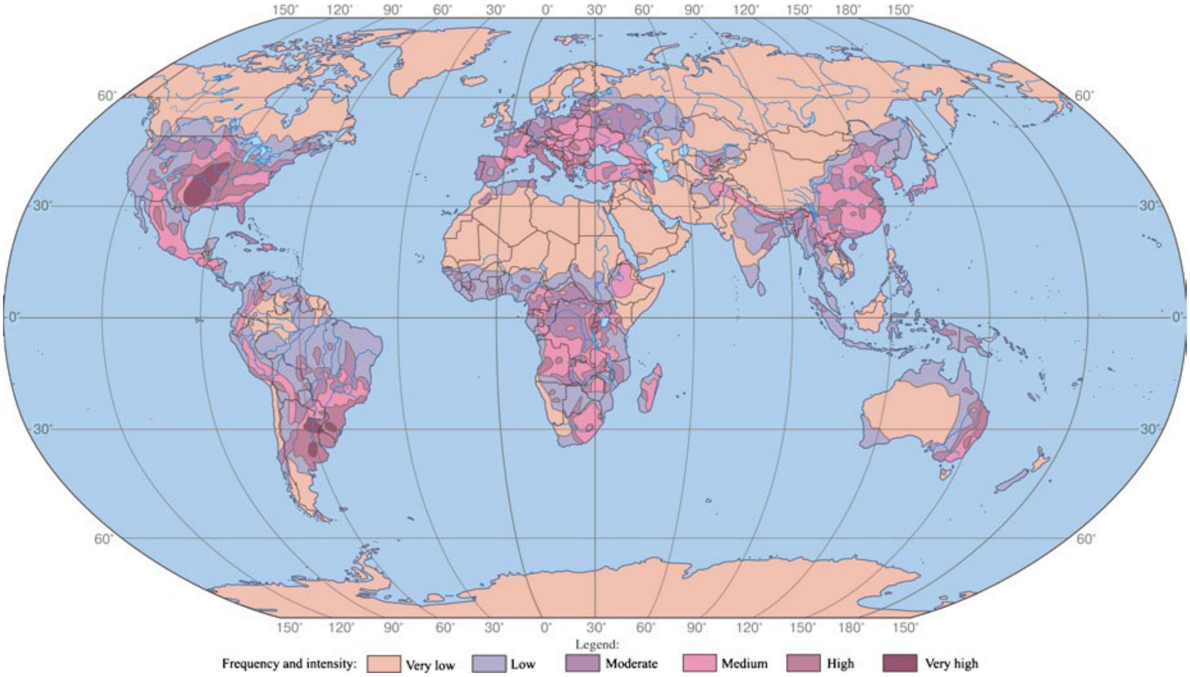

Fig. 3.9 Global distribution of hail storms (World map of natural hazards 2009. Reproduced with permission of Munich Re-Geospatial Solutions)

Photo 3.26 Hail is perilous for plant cultivation because it occurs during ripening, fructification, or blooming of vegetation. The United States annually loses 1% of national yields due to hail; the cultures most susceptible to it are wheat, maize, soybeans, and tobacco. The photo shows a hail-beaten maize field in the Midwest of the United States (Photo credit: University Corporation for Atmospheric Research, United States)

Photo 3.27 Of all kinds of transportation, aviation is affected the most by hail. Hail blows break windshields and the surfaces of airplanes. They cause flight performance to deteriorate. This photo shows a Saab-340 airplane with windowpanes damaged by hail during a flight from Wellington to Napier. The pilot had to land at the airport of Palmerston North, North Island, New Zealand (Photo credit: *Manawatu Standard* newspaper, Palmerston North, New Zealand, June 2000)

22 June 2003. The *heaviest hailstone* ever recorded was 1.0 kg (2.25 lb), in the Gopalganj District, Bangladesh, on 14 April 1986 (http://en.wikipedia.org/wiki/List_of_weather_records#Hail).

At times, hail threatens *people's lives*. It also affects many objects and *kinds of human activity*: (1) crop production, (2) livestock farming, (3) transport, and (4) industrial and civil engineering.

Cases of *loss of life* caused by hail are quite rare; however, such cases are known, and, in these cases, the threat to people increases with the size of the hailstones. For example, in 1888, about 250 people were killed by hail in New Delhi (India) in the course of a severe thunderstorm (Myagkov 1995).

The threat of hail to *crop production* is greatest during ripening, fruiting, or flowering of crops. For example, in 1939, one hail storm alone destroyed crops and plantings over an area of 100,000 ha in Kabardino-Balkaria (Russia) (Chirkov 1988). According to data presented by C. Smith (1978), the average *annual losses* related to hail in the United States are approximately 1% of the national yield. Hail inflicts substantial damage to orchards in northern Italy, vineyards in Caucasus, and tea gardens in Kenya, as well as to crops in South Africa and Argentina.

In *livestock farming,* hail causes the deaths of poultry and livestock. During a hail fall in 1939 near Nalchik, Russia, about 2,000 sheep were killed (Hydrometeorological dangers 2001).

Of all kinds of transport, *aircraft* suffer the most from hail. Hailstones break windshields and damage aerodynamic surfaces on aircraft, causing deterioration of their flight characteristics. This happens during flights and also at airports. An example of damage *in flight* is an event that occurred on 4 April 1977 in the United States. Hail forced a DC-9 jetliner to crash-land on a highway near New Hope (Georgia). As a consequence, 68 passengers were killed (Forces of nature 1998).

Cases of hail damage to aircraft on the *ground* are more numerous. For example, 18 aircraft at the Mineral Vody airport (Russia) suffered hail damage during a storm on 1 July 1991, and airport operations were interrupted for several hours (Epov 1994). The effects on *other kinds of transport* do not usually cause such severe consequences and are limited to broken windows and minor damage to vehicle bodies.

The effects of hail on *industrial and civil engineering* are mainly limited to broken windows and damaged roofs (Photo 3.30). The extent of damage depends on the sizes of the hailstones and the type of roofing material.

The effects of hail on human activities are illustrated by Photos 3.26–3.30.

Photo 3.28 Hail increases the slipperiness of roads and reduces visibility, heightening the possibility of accidents. This photo shows hail in Bogotá, D.C., Colombia, 3 March 2006 (Photo credit: http://en.wikipedia.org/wiki/Hail)

Photo 3.29 In regard to motor transportation, hail damages car windows, optical instruments such as headlights, and the car frame itself. This damage was caused by the hail of 5 October 2006 in Socorro, Texas (United States) (Photo credit: NOAA/NWS Weather Forecast Office, Hastings, Nebraska, United States)

Photo 3.30 Hail impacts industrial structures and dwellings by destroying glass objects and roofs made of low-strength material. The extent of damage depends on the sizes of hailstones and the kinds of materials used. The photo shows damage to windowpanes and roofs due to heavy hail. The left photo was taken in Oklahoma (United States) on 28 April 1956; the right one, in the same state on 1 July 1940 (Photo credit: U.S. National Oceanic and Atmospheric Administration)

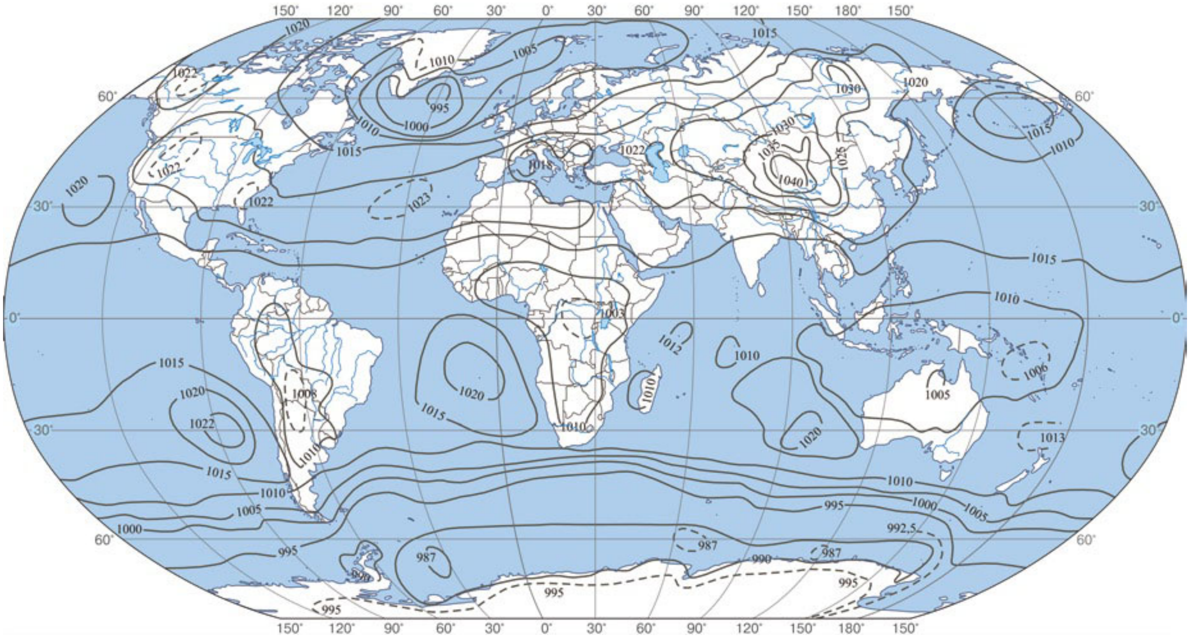

Fig. 3.10 Average pressure (mbar) at sea level in January (Adapted from Khrgian (1986). Reproduced with permission of Moscow State University, Russia)

3.8 Atmospheric Pressure

Atmospheric pressure is the pressure caused by the weight of the atmosphere. The continuous redistribution of atmospheric pressure on the Earth causes the atmosphere to be in constant motion. Nevertheless, one can identify several *constant zones* where the atmospheric pressure tends to be stable (Weisberg 1980): (1) doldrums, (2) subtropical high-pressure belt, (3) subpolar minimum, and (4) zones of relatively high pressure over the poles (Figs. 3.10 and 3.11). The *average annual surface pressures* in the northern and southern hemispheres are 983.6 and 988 mbar, respectively (Kagan 1992).

In spite of its apparent weightlessness, air is a comparatively *dense* gas medium. The weight of 1 m^3 of dry air at a temperature of 0°C *at sea level* is 1.293 kg. With increasing altitude, there is a rarefaction of air and reduction of its density. The same cubic metre weighs 319 g (four times less) at a *height of 12 km*, 43 g at a height of 25 km, and only 4 g at a *height of 40 km*. Nevertheless, the whole atmosphere exerts an enormous pressure on the Earth's surface, 10.3 t/m^2, while the pressure exerted on the whole Earth surface corresponds to the weight of five million cubic kilometres of water (Vovchenko 1985).

At each point in the atmosphere, there is a certain pressure; it *changes* uninterruptedly and is of a complex nature. The *average value* of atmospheric pressure at sea level for the Earth is 1,013 mbar, while on *land* (considering the elevation of continents above sea level), it is 982 mbar. The *record values* are 1,083.3 mbar (31 December 1968, Krasnoyarsky Krai, Russia) and 873 mbar (24 September 1958, the centre of a typhoon near the Philippines) (Reference book of necessary knowledge1994).

Annual variations in pressure in different regions of the Earth are great and change over time; however, they are characterized by *certain regularities*. For continents on the whole, pressure is greatest in summer and least in winter, whereas the annual amplitudes (differences between maximum and minimum monthly averages) increase as we move farther and farther away from the ocean (e.g. 9 mbar in Moscow, 22 mbar in Tashkent [Uzbekistan], and 40 mbar in the Gobi Desert).

Atmospheric pressure is one of the most important *weather parameters*. It is closely linked with most of the physical processes and phenomena that occur in

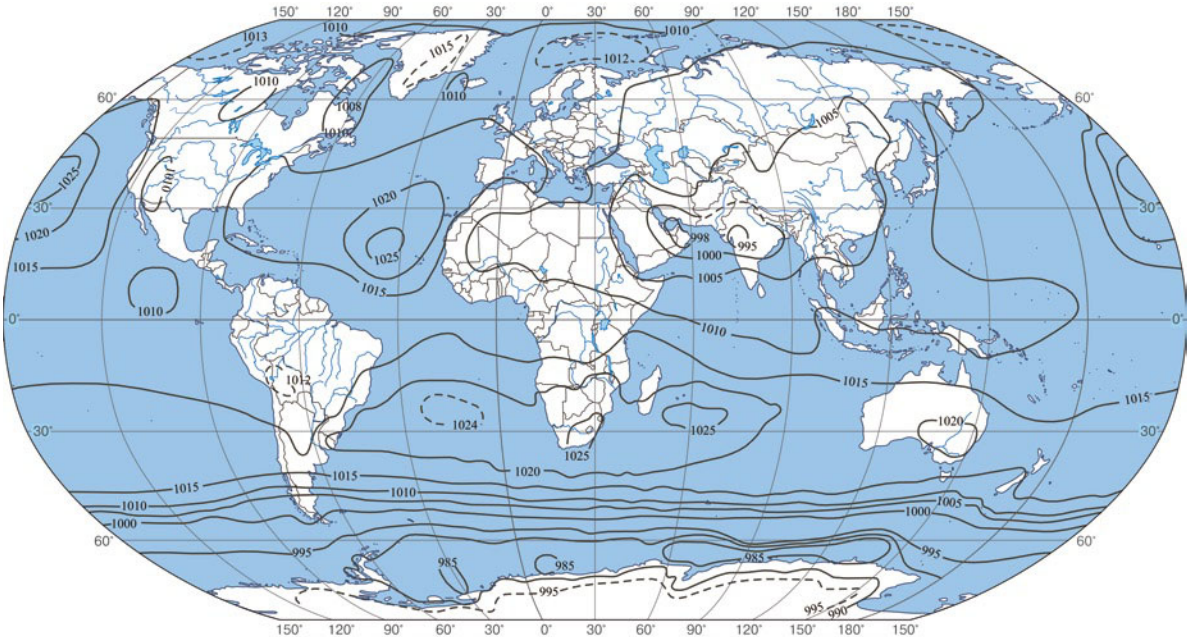

Fig. 3.11 Average pressure (mbar) at sea level in July (Khrgian 1986. Reproduced with permission of Moscow State University, Russia)

the atmosphere, especially with *wind*, *rain*, and *snow*. Therefore, atmospheric pressure is of pronounced significance for weather prediction, which, in turn, is of fundamental importance for most kinds of human activity. Atmospheric pressure is also of significance for *air transport*, because it affects the lifting capacity of the wings of an aircraft.

The *well-being* of people depends, to some extent, on atmospheric pressure. When it falls, gases in the gastrointestinal tract expand, resulting in expansion of organs. Often, it causes *dysorexia and indigestion*. In addition, a high position of the diaphragm related to decreased air pressure can affect *respiration and impair the functioning of the cardiovascular system*.

When atmospheric pressure changes abruptly, a *sensation of deafness* often arises. The *feeling of illness* increases the vulnerability of humans operating high-end technologies, which can increase the number of technical accidents. For example, the number of car crashes in Switzerland increases by 21% when the atmospheric pressure increases sharply (Myagkov 1995).

3.9 Wind

Wind is a motion of air relative to the Earth's surface. The *initiation* of the wind is related to the non-uniform heating of the Earth due to cloudiness, heat accumulation by water bodies, surface relief, and a number of other causes. Wind is closely related to atmospheric pressure; it is directed from areas of high pressure to areas of low pressure. Mean annual wind velocity is shown in Fig. 3.12.

The *wind direction* is the direction from which it blows. In order to indicate a direction, eight basic bearings – north, north–east, east, etc. – and eight intermediate bearings between them are usually used. The average near-surface wind speed is about 10 m/s (36 km/h) (Nikolaikin et al. 2003).

Every obstacle the wind encounters modifies the wind field. Flowing around the obstacle, the wind weakens before it but intensifies on its sides. Immediately behind the obstacle, a *windless region* forms where the wind speed *decreases* sharply. When the air flow goes through a narrow spot (approaching mountain ranges, straight between high islands, etc.),

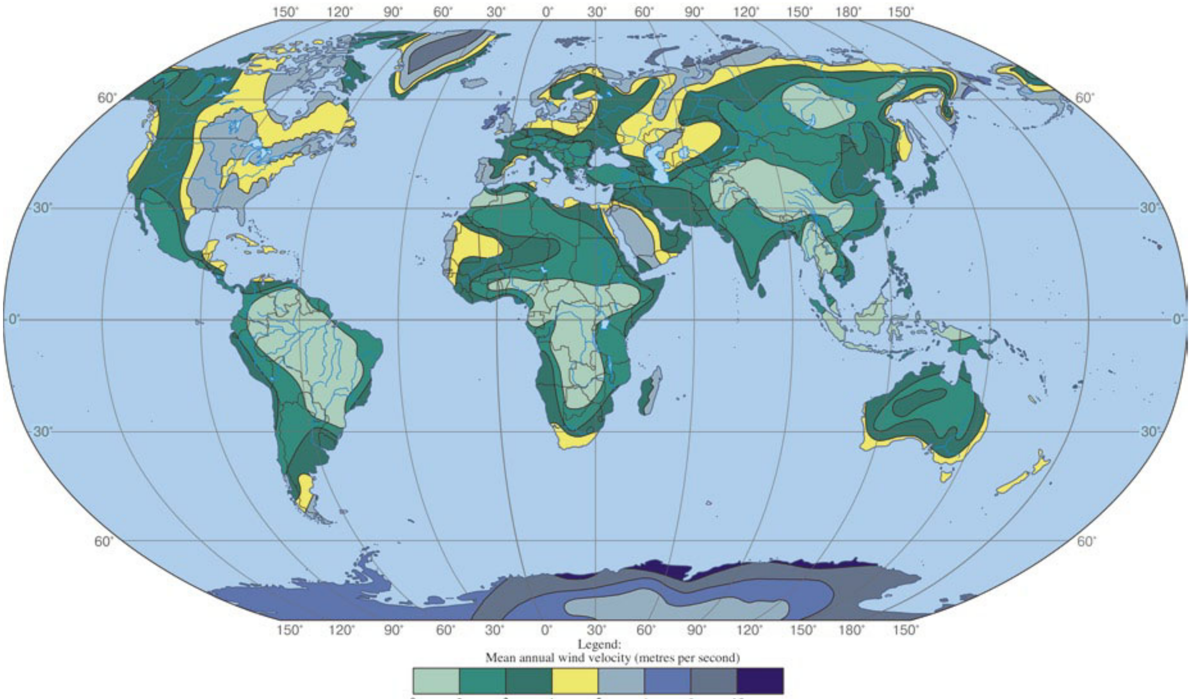

Fig. 3.12 Mean annual wind velocity (Resources and environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of Sciences)

the wind *intensifies* to a considerable extent. This intensification occurs because the speed of the wind increases as a volume of air moves across a decreasing cross section (Khromov and Petrosyants 2001).

Atmospheric circulation is caused by global and local winds. *Global winds* include *monsoons* (seasonal winds caused by the transformation of the pressure field due to differences in the heating of continents and oceans in the course of the year) and *trade winds* (winds blowing from high-pressure areas towards the equator). *Local winds* are the numerous winds characteristic of particular regions.

An important constituent of the atmospheric circulation is the *jet streams*. These are relatively narrow and speedy air streams; they occur at altitudes of 6–30 km. The lengths of jet streams are thousands of kilometres, and their vertical thicknesses are up to 10–15 km, while the widths reach about 1,000 km (on average, 300–500 km). The *speeds* of jet streams are generally 15–50 m/s; however, they can reach 133 m/s (480 km/h) (Encyclopaedia ocean–atmosphere 1983; Geographical encyclopaedic dictionary 1988).

Wind has the greatest effects on the following *objects and kinds of human activity*: (1) air transport, (2) water transport, (3) crop production, (4) livestock farming, (5) housing development, (6) transmission lines, (7) bridges, (8) military activities, and (9) recreational activities.

For aviation, the following *characteristics* of wind are of significance: (1) wind direction and speed, (2) wind shear (changes in wind speed and direction over a unit distance; vertical and horizontal wind shears occur), and (3) turbulence (deviation of the air stream speed from the steady-state regular regime).

Wind *direction* and *speed* exert some effects on flight speeds relative to the Earth surface – reducing it or increasing it depending on the difference between the course of the airplane and the wind direction. At present, long-range flights are planned with consideration to wind predictions for different heights, which allows pilots to choose the optimal altitude and track of a flight. The best choice of a track reduces the flight time in spite of the distance to a destination.

Wind shear can be dangerous to air travel. According to ICAO (International Civil Aviation Organization) statistics, between 1970 and 1985, there were 28

Photo 3.31 The impacts of wind on human activities are multifarious. Damage to vehicles by falling trees is widespread. The photo shows a Jaguar crushed by a falling tree (Photo credit: Joseph O'Brien, USDA Forest Service, Bugwood.org)

aviation accidents with 700 fatalities caused by low-level wind shear (Guan and Yong 2002).

The degree to which an aircraft is affected by turbulence depends on *three factors* (Encyclopaedia ocean-atmosphere 1983): (1) airplane speed (high-speed airplanes are exposed to more turbulence), (2) aircraft mass (heavy aircraft move more smoothly than light aircraft), and (3) flexibility of wings (aircraft with rigid wings are more sensitive to turbulence because flexible wings are capable of impact damping). Besides sometimes creating emergency conditions, turbulence creates *inconvenience* from the viewpoint of the passengers' comfort and *worsens the operating characteristics* of gas turbine engines.

In aviation statistics, accidents caused by turbulence are combined with incidents due to crosswinds (without change in wind direction or speed). In total, 40 such accidents have been recorded, in which 1,041 people have been killed.

In the times of sailing ships, the impact of the wind on *water transport* was cardinal. The wind still does have some influence on the motion of vessels. Favourable winds increase the speed of ships by about 1%, whereas adverse winds reduce it by 3–13%, depending on the dimensions of the ship and the cargo it is carrying (Smith 1978). The role of wind is also of no small importance for *motor* and *rail transport*. Depending on the wind direction, it influences the travel speed or vehicle stability, quite often overturning vehicles.

The effects of wind on *crop production* are quite diverse, and, depending on concrete conditions, they may be both positive and negative. The *positive effect* of the wind is that it transfers humid air from oceans and seas to continental regions, providing vegetation with moisture. The *negative impact* is the intensification of non-productive evaporation from the soil surface, which exacerbates drought. Strong winds can flatten crops and break fruit trees.

The wind exerts pronounced effects on *industrial* and *civil engineering*. All structures towering above the ground surface experience wind loads. Wind increases heat losses and wind loads, which are especially important for *high-rise structures* (television and radio masts, smokestacks, transmission towers, towers, etc.).

In addition to the dynamic pressure, the influence of wind on *transmission lines* and *bridges* is related to its wave nature. Additional loads related to the vibratory motions of wires appear. As for bridges, the basis of the impact is sometimes an *unfavourable coincidence of its characteristics* with the vibration amplitude of a bridge rather than high wind speeds. In the literature, at least ten similar events are described. The destruction of the Tacoma Narrows Bridge (Washington state, United States) on 7 November 1940 is most well known. The cause of the accident was an abrupt change in the mode and shape of oscillations of the bridge (Rocar 1959).

Photo 3.32 Trees often fall on houses due to strong winds. The photo shows a fallen elm (*Ulmus spp.* L) that damaged a house in Greer, South Carolina (United States) (Photo credit: Randy Cyr, Greentree, Bugwood.org)

Photo 3.33 In many cases, small houses are damaged by strong winds directly. The photo shows a house in Honduras that was blown off its foundation by Hurricane 'Fifi'. (Photo credit: UNESCO, M. Ginies, 1974)

Military activities also depend on the wind to some extent. As early as the Second World War, an attempt was made in Japan to use the jet streams to bomb the United States. In 1944, the Japanese launched more than 10,000 balloons carrying firebombs in the direction of the United States. It was assumed that balloons captured by the jet streams would be carried to US territory. The required balloon flight altitude was automatically maintained by special devices. About 10% of the balloons were successful, although, on the whole, the damage inflicted proved to be small (Weisberg 1980). In addition, the wind determines the conditions for flights of aircraft, missiles, and ballistic rockets.

Photo 3.34 The town of Boulder, Colorado (United States), is situated at the eastern foot of the Rocky Mountains. These relief conditions modify atmospheric circulation. That is why the wind blowing from the slopes often becomes stronger in orographic narrows, sometimes reaching speeds of more than 160 km/h. The photo shows an upturned plane at the local airport (Photo credit: Edward Zipser, University Corporation for Atmospheric Research, United States, 17 January 1982)

The wind plays a great role in *recreational activities*. For example, when, in summer, the mistral begins to blow near the coasts of Provence in France, the temperature of seawater is abruptly reduced: For 24 h, it may decrease from 23°C to 16°C, which sharply restricts the possibilities for bathing (Ehrhardt and Seguin 1984). The wind is important for some sports (sailing, parachuting, gliding, downhill skiing, etc.).

To the extent *wind farms* are used to generate electric power, electric power generation depends on the wind.

The effects of wind on human activities are illustrated by Photos 3.31–3.34.

3.10 Temperature

The following *factors* influence air *temperature distribution* on Earth (Figs. 3.13 and 3.14): (1) latitude (generally, temperature drops from the equator towards the poles in accordance with the distribution of the radiation balance on the Earth's surface), (2) distribution of land and water, (3) regional disturbances caused by the presence of snow or ice cover, mountain ranges, warm and cold oceanic currents, etc., and (4) peculiarities of general atmospheric circulation.

The *lowest air temperatures* on the Earth are observed in Antarctica, north-eastern Asia, Baffin Island, and Greenland. The *maximum temperatures* are characteristic of North Africa (Libyan Desert, Sahara), California (Death Valley), central provinces of Mexico, southern Iran, and north-western Australia.

The *absolute minimum* temperature (−89.2°C) was recorded at the Vostok Station (Antarctica) on 21 July 1983. As an *absolute maximum* for the Earth, a temperature of 58°C was recorded at Al'Aziziyah, Libya, on 13 September 1922. As to *average annual values*, the highest temperature (31°C) is noted at Lu,

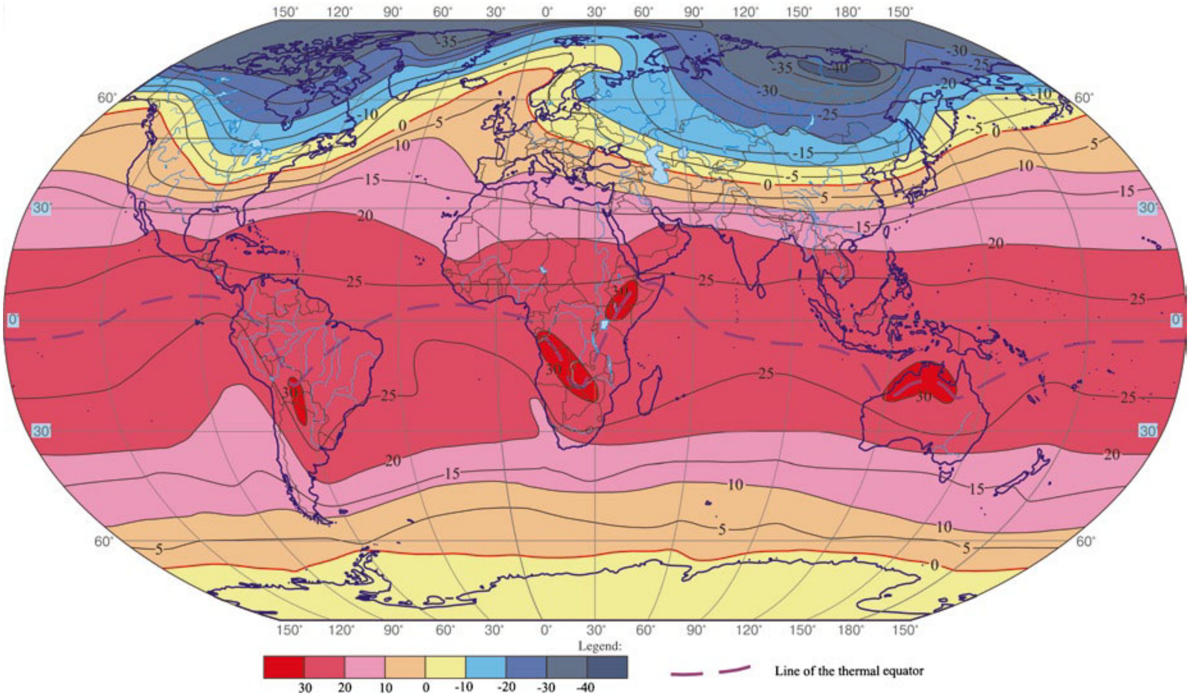

Fig. 3.13 Air temperature in January reduced to sea level (Adapted from Harvey (1982), Resources and environment 1998)

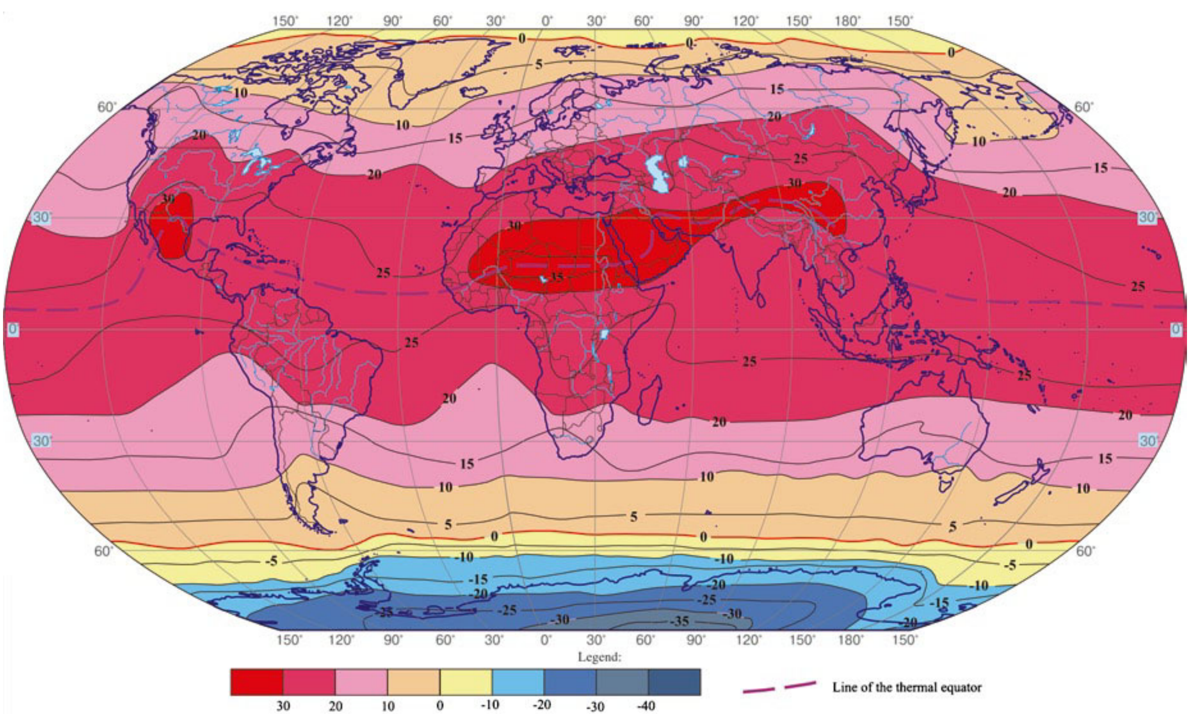

Fig. 3.14 Air temperature in July reduced to sea level (Adapted from Harvey (1982). Resources and environment 1998)

Somalia, while the lowest one (–55.6°C) is registered at the Vostok Station (Antarctica).

An important index of atmospheric thermal conditions is the *annual amplitude* of air *temperature* (difference between the average temperatures of the warmest and coldest months of the year). This value is minimal in the oceanic areas near the equator and in mountainous regions of the tropical zone. For example, the annual amplitude at the capital of Ecuador (Quito) is only 0.2°C (Climatology 1989). The annual amplitude reaches maximal values (60°C) in north-east Asia.

Light *frosts* are also a significant temperature phenomenon. They occur when air temperature drops to 0°C and lower, but daily average temperatures are above 0°C, that is, in spring and in autumn.

The following *characteristics of air temperature affect* human activities: (1) extreme values, (2) prolonged periods with deviations from average annual values, (3) peculiarities of temperature dynamics in diurnal variations, (4) abrupt temperature variations, and (5) light frosts. This meteorological parameter influences, to a considerable degree, the well-being and mortality of humans, as well as a number of objects and kinds of human activity: (1) crop production, (2) livestock farming, (3) transport, (4) industrial and civil engineering, and (5) forestry.

Temperature has important effects on the *human organism*. Human resistance to the effects of *heat* is much greater than resistance to *cold*, because transpiration makes it possible to dissipate heat. Not all people are able to adapt to the prolonged impact of temperatures beyond the limits of the comfort zone, which, according to data of D.Yu. Fedyunina (2004) is between 17°C and 27°C with moderate humidity levels and air movement. Air temperatures especially concern visitors to a region, which is evident in the *tropical* and *cold* diseases of migrants. The first are expressed in the loss of salt and heat exhaustion, and exponential growth of mortality, while the second exacerbate cardiovascular and other functional disorders (Myagkov 1995).

Extreme temperatures cause considerable mortality. For example, the *intense heat* in the summer of 1980 resulted in the loss of at least 1,250 lives in the United States; in India, it killed 3,500 people (Natural-science foundations of life stability 2003). In July 1995, heat caused the loss of 4,600 lives in Chicago (Illinois, United States) (McMichael 2000). It is estimated that, in the United States alone, heat killed 8,015 people during the period 1979–1999 (Natural-anthropogenic processes and ecological risk 2004).

Mortality related to *extremely low temperatures*, as a whole, is less, and it depends not so much on the deviation value itself as on the adaptation of people to it. For example, more than 200 people were killed by the cold in India in January 1989, and more than 200 people were killed in Mexico in January 1984 (at air temperatures of about 0°C). In the United States, about 230 people were killed in January 1984, and in February 1989, another 230 people were killed when temperatures reached −40°C (Myagkov 1995). For the Earth as a whole, *mortality from extreme temperatures* is estimated by us at 500–600 people per year (Govorushko 2009c).

Sudden changes in temperature also exert important effects on the human body. For example, when the air temperature rose from −43.6°C to +6°C on one night in January 1780 in Saint Petersburg, 40,000 people came down with flu (Assman 1966).

The impacts of temperature on *crop production* are important, and practically all factors contribute to them. Considerable losses are inflicted by *light frosts*; light frosts in the late spring and early autumn (in the subtropics, winter frosts also) are dangerous primarily for agricultural plants. The damage inflicted by light frosts depends on the stage of development and the plant species. For most species, the flowering period is the most vulnerable stage of development.

Light frosts result in *significant economic losses*. For example, the light frost cost in the United States in 1975 was estimated at US$1.1 billion, and roughly half of the losses occurred at orchards (Smith 1992).

Extreme temperatures are also harmful for crop production. For example, a reduction in soil temperatures at the depth of the tillering node of winter crops below critical values (−16°C to −18°C for most varieties of winter wheat, −22°C to −25°C for winter rye) results in their winter-killing. At high soil temperatures, there is degeneration of potato tubers (Chirkov 1988).

Anomalously cold summer months cause a sharp reduction in productivity. For example, during periods with extremely cold summers (1782–1787, 1833–1839, 1866–1869), the population of Japan decreased by 10% due to bad rice harvests (Dyakonov and Anoshko 1995). On the other hand, anomalously high air temperatures in the nineteenth century time and again caused a drying of the plains in the Midwest (United States). In

Photo 3.35 Light frosts in the late spring and early autumn are dangerous primarily to plants. The photo shows an early autumn frost in 2006 near Toronto, Canada (Photo credit: Ilan Kelman (http://www.ilankelman.org))

many tropical areas, the development of agricultural plants is limited primarily by high temperatures.

Temperature conditions are of great importance to crop development. The physiological processes in plants occur only in the range of optimum temperatures between the biological minimum and the biological maximum. These characteristics are different for different plants. For example, the biological minimum for sprouting of seeds of spring crops is 3–5°C, while it increases to 12–15°C for heat-loving cultures (Chirkov 1988). In this respect, rice, sugar cane, and cotton plants suffer even at 15°C (Harwell and Hutchinson 1988).

Temperature variations over shorter periods are also of pronounced importance. For example, the productivity of tomatoes and potatoes increases if the nights are relatively cool (10–15°C) while days are warm. For increasing sugar beet yields, it is necessary that temperatures during the growth period exceed 20°C, but that during sugar formation in the beet, they are lower than this value (Betten 1985).

Temperature conditions are also of importance for crop production from the viewpoint of the development of *injurious insects* and *diseases*. For example, the developmental time for locusts from the larval stage to the adult stage at air temperatures of 22–27°C is about 50 days, but it is only 20 days at temperatures of 32–39°C. Similarly, the beet webworm caterpillar (*Margarita sticticalis* L.), which damages sugar beets, sunflowers, watermelons, and other crops, develops over 29 days at 15°C, but over only 6 days at 32°C (Chirkov 1988).

Temperature conditions determine, in large part, the state, behaviour, and productivity of *agricultural animals*; here, the *extreme values are* especially critical. Animals are susceptible to high temperatures, as their heat exchange is disturbed. Torrid weather oppresses sheep, slowing down their fattening. At the same time, torrid weather is favourable for bee farming because the high temperatures increase the activity of bees. Extremely low temperatures are also dangerous for *livestock farming*. For example, near Karapinar (Turkey), only 14,000 sheep of 300,000 survived the severe winter cold in 1938 (Furon 1966). Cold temperatures are especially unfavourable during the period of *sheep shearing*.

Temperature conditions are of great importance for transport operations, especially for *air* and *motor* transport. Low temperatures can make it difficult to start engines due to reductions in the capacity of batteries, and they can cause fuel and hydraulic systems to leak due to loss of elasticity. The thaws after severe frosts can result in seizure of driving mechanisms, formation of ice crystals in fuel lines, and the plugging of pipelines and filters.

The effects on *rail* and *water transport* are generally caused by temperature extremes. For example, the rails in railways and landing strips of airfields in central England were deformed in July 1990 at a temperature of only 37°C (Myagkov 1995). In the winter of 1956,

Photo 3.36 Temperature conditions are important for forestry. Sharp temperature drops often result in the formation of frost fissures in tree trunks and degradation of the quality of the wood. The picture shows frost injury of an Austrian pine (*Pinus nigra* Arnold) (Photo credit: USDA Forest Service, North Central Research Station Archive, Bugwood.org)

anomalously low temperatures caused the Rhine River to freeze, paralyzing the vital route for river navigation in Germany (Forces of nature 1998).

Temperature conditions exert marked effects on *construction operations*. Low temperatures result in difficulties and stoppage in setting concrete; delays in excavation operations; complication of painting, plastering, and brick masonry activities; and freezing of unprotected water pipes and stacked materials.

To some degree, temperature conditions are also of importance for *forestry*. Sharp temperature drops often result in the formation of frost fissures in tree trunks and degradation of the quality of the wood.

In addition, air temperature has a pronounced effect on *transportation of some cargoes*. The rates of many microbial and chemical reactions double when the temperature increases by 10°C; therefore, for the transportation of meat, fish, fresh fruits, and vegetables, insulated containers are used. Low temperatures are also dangerous for many cargoes (fruits, vegetables, potatoes, etc.).

Extreme temperatures can create difficulties for *military activities*. For example, an ammunition depot in Burkina Faso (Africa) exploded in 1990, because walls overheated due to the intense heat (up to 50°C) (Myagkov 1995).

The influences of temperature on human activities are illustrated by Photos 3.35 and 3.36.

3.11 Solar Radiation

Solar radiation is the electromagnetic and corpuscular radiation of the Sun. The *annual distribution* of solar radiation on the Earth's surface is not entirely dependent on latitude, as there are differences in cloudiness and transparency of the atmosphere (Fig. 3.15).

Solar radiation is the basic and essentially the sole *source of energy* for atmospheric processes. It is categorized as *direct*, *diffuse*, and *total* solar radiation. Direct solar radiation (i.e. immediately from the Sun disc) reaches the upper limit of the atmosphere. If its value there is taken as 100%, then 42% of this amount is reflected by clouds and dust in the atmosphere, 10% is absorbed and dispersed in the atmosphere, and only 48% of the radiation reaches the Earth's surface (Allaby 1996).

The spectrum of solar radiation is divided into three parts: (1) ultraviolet, (2) visible, and (3) infrared. *Ultraviolet radiation* has wavelengths of 0.01–0.39 μm and comprises 9% of the radiant energy from the Sun; it is not perceived by the eye. *Visible light* is radiation with wavelengths of 0.40–0.76 μm. The wavelength of 0.40 μm corresponds to the colour violet, while 0.76 μm corresponds to red. The entire visible spectrum falls between these two wavelengths. 47% of the solar radiant energy falls in this part of the spectrum. *Infrared* radiation has wavelengths greater than 0.76 μm and more (up to several hundred micrometres). Just as with ultraviolet radiation, infrared radiation is invisible. Infrared radiation comprises 44% of all solar radiation (Khromov and Petrosyants 2001).

The direct solar radiation reaching the Earth's surface is partly reflected from it. The measure of reflected radiation is the *albedo*, the ratio of the intensity of

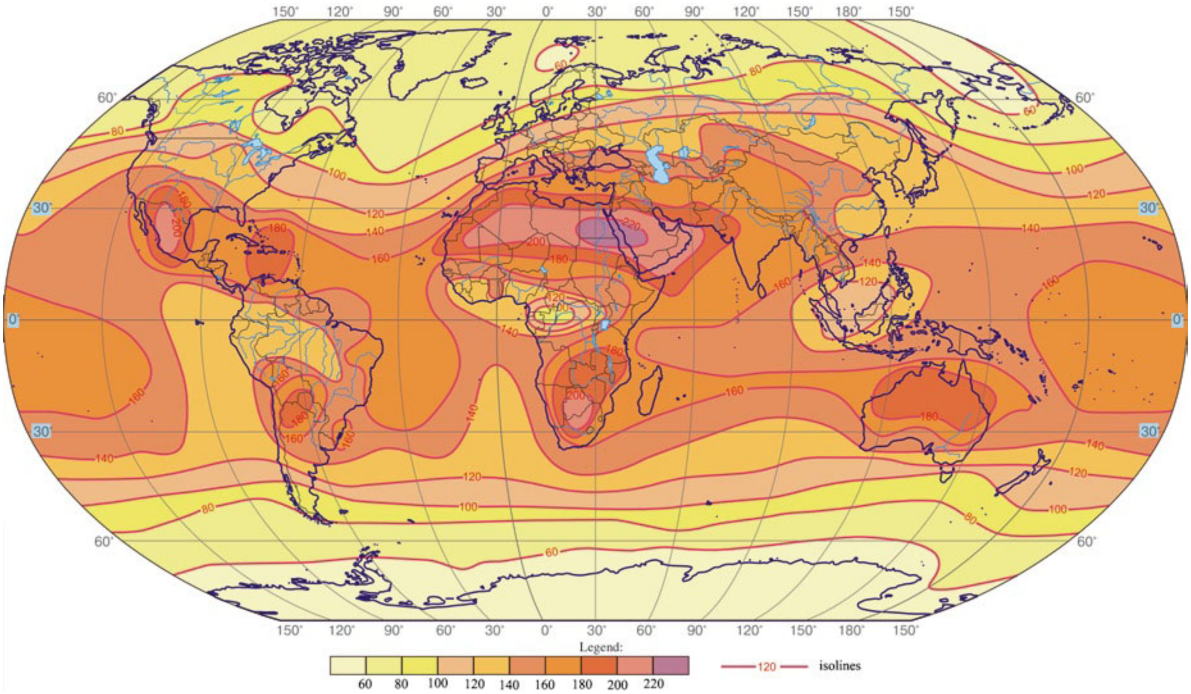

Fig. 3.15 Average annual amount of solar radiation reaching the Earth surface in Kilocalories per square centimetre (M. Allaby Basics of Environmental Science (1996, p. 38). Reproduced with permission of Routledge)

radiation reflected by the surface to the intensity of radiation arriving at the surface. The *albedo of the Earth*, including the atmosphere, is 34% (Weisberg 1980).

The influence of solar radiation on human activities is generally related to its *thermal and light properties*. In addition, solar radiation has a number of other properties. It may exert *chemical, antirachitic, inflammatory (sunburn), bactericidal, carcinogenic, mutagenic*, and other effects.

Solar radiation is an important factor affecting people and a number of objects and *kinds of economic activity*: (1) crop production, (2) livestock farming, (3) civil and industrial engineering, (4) recreational activities, (5) medical care, (6) power engineering, and (7) mining operations.

The influence of solar radiation on *humans* is exerted by practically all factors. The *thermal effect* determines, in many cases, the comfort or discomfort of people, especially outdoors. *Sunburn* is caused by short-wave ultraviolet radiation. The *sensitivity to suntan of individual parts* of the human body decreases in the following *sequence*: breast, stomach, back, neck, face, and upper and lower extremities. The sensitivity of the face is about 25%, while the sensitivity of the neck is approximately 50% of the sensitivity of the breast. Sensitivity depends on hair colour, sex, and age. The highest sensitivity to ultraviolet radiation is characteristic of red-haired people; blonds, brown-haired persons, and brunettes follow. Women are more sensitive to suntan than men, and children are more sensitive than adults (Ultraviolet radiation of the Sun and sky 1968).

The *bactericidal action* of solar radiation is also caused by ultraviolet rays. It has been proved that almost all bacteria can be killed or weakened by ultraviolet radiation. It improves an organism's resistance to infections and suppresses the development of atherosclerosis and hypertension (Fedyunina 2004).

Ultraviolet radiation has an unfavourable effect on the *eyes*. At or above a certain radiation dose, inflammation of the cornea (keratitis) or mucous membrane (conjunctivitis) develops after a period of several hours. The acute pain and annoying sensation of a foreign body being in the eye last 1–2 days (Ultraviolet radiation of the Sun and sky 1968).

Photo 3.37 Solar radiation is of paramount importance for recreational activities, especially for seaside resorts. The photo shows people who became sunburnt on the south coast of England, Dorset County (Photo credit: Ilan Kelman (http://www.ilankelman.org), end of July 2003)

Solar radiation exerts an *antirachitic action*. The development of rachitis (rickets) is related to the formation of vitamin D in an organism. Ultraviolet rays are able to cure and prevent rachitis through promoting vitamin D formation in humans (Fedyunina 2004).

The *carcinogenic action* of solar radiation is also related to ultraviolet rays. Skin cancer occurs in people of all nations; however, incidences of the disease in populations of different countries vary greatly. People with light skin are more susceptible to this disease. In the Hawaiian Islands, skin cancer occurs among whites 42 times more often than among the native population. In Australia, the Irish and Scottish are more susceptible than Germans and Scandinavians; the English and Slavs follow, and this disease is extremely infrequent among the Chinese and native populations (Ultraviolet radiation of the Sun and sky 1968). Thus the ultraviolet radiation of the Sun has profound effects on people.

The effects produced by solar radiation on *agriculture* are great. The radiation is a major factor in plant growth because it controls both *photosynthesis activity* (through the length of daylight hours) and *transpiration* (through the amount of incoming thermal energy) of plants. Every branch of a growing plant is based on direct or indirect use of solar radiation and transformation of it into the organic product. Taking into account the radiation conditions is also necessary in planning the water discharge for field irrigation.

On the whole, plants are very sensitive to solar radiation. Too long and powerful irradiation delays photosynthesis and causes chlorophyll to decay, resulting in the yellowing and loss of leaves. Cases of burns of the bark of fruit trees are typical. The influence of solar radiation on *livestock farming* lies in the fact that, as a result of long stays in the sun, livestock suffer from sunstrokes; they gain less weight, and a number of other important characteristics deteriorate.

The effects of solar radiation on *industrial and civil engineering* occur through thermal and light action. Thermal effects determine, to a large extent, the temperature behaviour of buildings; heat from the Sun can be harmful during the frost-free season of the year and result in overheating of premises. On the other hand, heat from the Sun can be a favourable factor in winter, reducing heat losses and contributing to fuel savings. The *light* from the Sun regulates the length of the days.

Photo 3.38 The heat of solar radiation is applied to obtain salt from seawater. A distant view, the photo shows spacious areas of evaporation ponds on the western coast of South Korea near Seoul. The water goes into the structures and soon vapourizes due to solar radiation, while the salt stays on the bottom and is extracted. Then the new cycle begins (Photo credit: H.J. Walker, 1 July 1979)

Photo 3.39 Solar radiation usually has positive influences on power generation. It is increasingly used for generating energy for industrial and communal needs. Electric power stations, helio-heaters, solar structures for accumulator charging, and other devices are widely applied. The photo shows solar collector panels used to provide a hot water supply in north-eastern China (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 25 August 2007)

Photo 3.40 Cloudiness extensively affects aviation. It complicates orientation by pilots flying without navigation instruments and makes landings and take-offs more difficult. The photo shows a plane flying in conditions of dense cloudiness (Photo credit: University Corporation for Atmospheric Research, United States)

The quantity of solar radiation is of great importance for *recreational activities*. Longer days, along with the daily high temperatures, are the most important factors for all kinds of recreation on the beach, including swimming and the enjoyment of seaside resorts.

The use of solar radiation in *medicine* is related to its numerous useful properties (antirachitic, suntan, bactericidal) considered above. Many of these properties are widely used in the practice of patient care and prophylaxis.

The effects on *power engineering* are basically positive and lie in the fact that solar radiation is being used more and more as a source of energy for industrial and domestic purposes (power plants, helio-heaters, refrigerators, solar kitchens, solar stations for accumulator charging, etc.).

The role of solar radiation in *mining operations* is strictly positive. Its thermal action is used for vapourization, which is most often used for extracting salt from seawater (Photo 3.38). For example, in China – world leader in this field – the area of salt evaporators is 430,000 ha. In 1997, more than 29 million tons of salt were produced there (Bocharnikov et al. 2006).

In addition, solar radiation (ultraviolet part of the spectrum) has a destructive effect on *synthetic materials* and *lacquer coatings,* accelerating their ageing. It is used for bleaching substances and for drying and sterilizing materials.

The influence of solar radiation on human activities is illustrated by Photos 3.37–3.39.

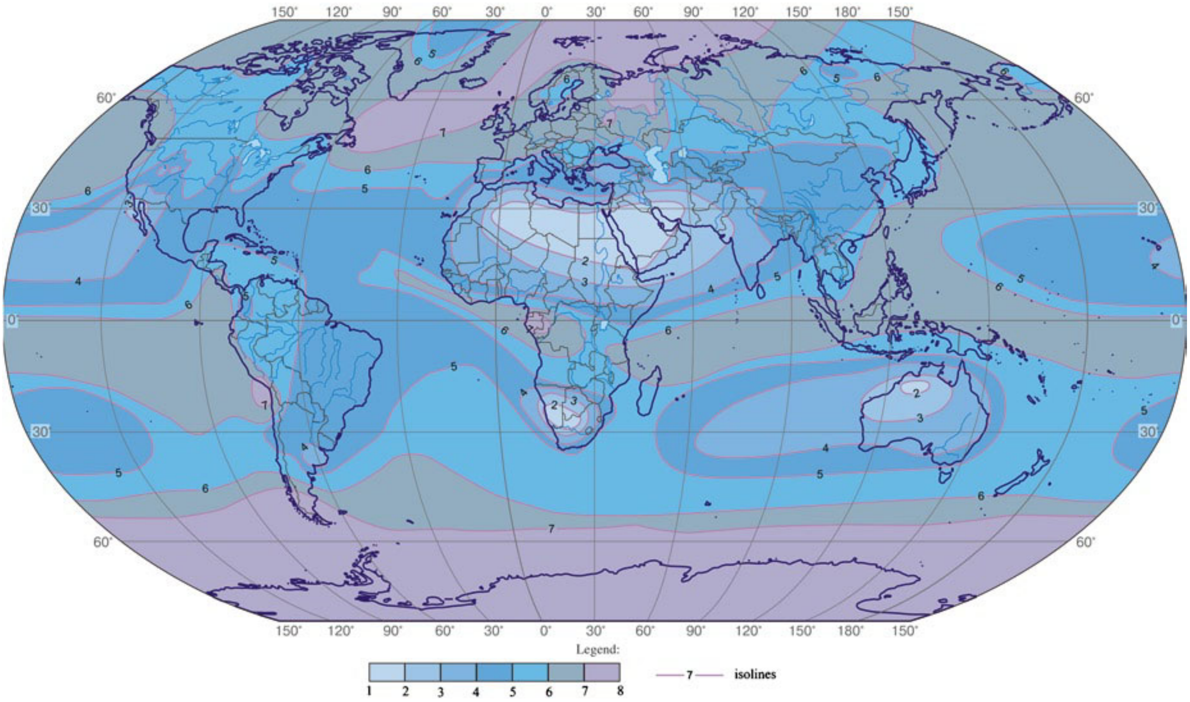

Fig. 3.16 Average annual cloudiness in tenths (Khromov and Mamontova 1974. Reproduced with permission of Moscow State University, Russia)

3.12 Cloudiness

Cloudiness is an association of clouds observed on the dome of the sky. A general idea of the *geographical distribution of cloudiness* is given by Fig. 3.16. That portion of the sky where cloud cover is present is usually measured in tenths of the sky that is covered.

The cloudiness over the sea is greater than that over the land. For both the northern and southern hemispheres, the cloudiness over the sea is 6.2 tenths, while over the land, it is 5.3 tenths. For the *globe as a whole*, the cloudiness is about six-tenths; that is, approximately 60% of the planet surface is cloudy at any particular time.

Among the *most cloudy localities* on Earth are the northern Pacific and Atlantic Oceans, north-western Europe, Japan, and Antarctica. The *least cloudy territories* are the subtropical deserts of the northern and southern hemispheres. For example, the annual average cloudiness in Aswān (Egypt) is 0.5 tenths (Khromov and Petrosyants 2001).

Every cloud is an association of tiny water droplets. The *sizes of the droplets* vary within wide limits – from fractions to hundreds of micrometres (i.e. from ten thousandths to tenths of a millimetre). Clouds over land generally consist of drops of 3–4 to 20–30 μm in size. The *numbers of droplets* are, on average, 800 drops per cubic centimetre in the lower troposphere to 100 drops/cm^3 within the upper layers of the troposphere (Clouds and cloudy atmosphere 1989). In typical marine clouds, the concentrations of drops are several tens per cubic centimetre (Rogers 1979).

The overwhelming majority of clouds are concentrated in the troposphere – the lower layer of the atmosphere, having thicknesses of 8–10 km in the polar regions to 16–18 km in the tropics. The diverse types of clouds in the troposphere are strictly categorized by the *International Cloud Classification* system. According to this system, all clouds are subdivided into the *ten cloud genera*: (1) cirrus, (2) cirrocumulus, (3) cirrostratus, (4) altocumulus, (5) altostratus, (6) nimbostratus, (7) stratocumulus, (8) stratus, (9) cumulus, and (10) cumulonimbus.

Cloudiness is closely related to *humidity* (the higher the humidity near the Earth's surface, the lower the cloud base). Therefore, the height of the cloud base in

Florida in summer is 600 m, while in Arizona where the air is drier, it is five times higher (Betten 1985).

Clouds are very dynamic formations (Clouds and cloudy atmosphere 1989). Even in long-lived clouds, continuous evaporation occurs, and new cloud elements appear. The *lifetime* of the 'average' cloud is 10–45 min (Skorer 1980).

Most precipitation falls from cumulonimbus, nimbostratus, and deep, well-developed (in the vertical) cumulus clouds (Astapenko 1986). Clouds are of pronounced significance in the *heat balance* of the Earth. On one hand, clouds *prevent the loss of heat* radiated by the Earth's surface. On the other hand, they *reflect incoming solar radiation*. The albedo of clouds varies from 10% to 90%. Generally, the smaller the drops and the greater the amount of liquid moisture in a cloud, the higher the albedo (Encyclopaedia ocean-atmosphere 1983). On the whole, clouds act to *cool* the Earth.

Clouds differ from each other in their *electrical properties*. The maximum electric field strength is characteristic of cumulonimbus and deep cumulus clouds. On average, the electrical activity of clouds *increases* from the high latitudes to the low latitudes.

Annual variations in cloudiness differ strongly in different climatic zones. In the high and middle latitudes, over the ocean, their amplitudes are very small, with a peak in summer or autumn and a minimum in spring. In the Faeroe Islands, cloudiness is 7.9 tenths in August and 7.0 tenths in April. In the continental regions, the amplitudes are greater. For example, in Tashkent (Uzbekistan), it is 6.4 tenths in January and 0.9 tenths in July (Khromov and Petrosyants 2001). *Diurnal variations* in cloudiness are quite complex and depend strongly on the kind of cloud.

Cloudiness plays a *significant part* in aviation, crop production, recreational activities, solar power engineering, industrial and civil engineering, and radio communication.

Cloudiness may create difficulties for the *take-off and landing of airplanes*, and it complicates in-flight spatial orientation for pilots flying without instruments. Special danger is represented by cumulonimbus and deep nimbostratus clouds that reduce illumination to twilight levels.

The effects on *crop production, recreational activities, and solar power engineering* are related to the reduction in incoming solar radiation. In *crop production*, cloudiness reduces energy absorption by the chlorophyll of plants and reduces the transpiration rate. The influence on *recreational activities* is related to interruptions in the use of ultraviolet radiation (bactericidal, suntan, and antirachitic actions). The importance for *solar power engineering* consists of a decrease in the *light energy* that can be transformed into photochemical, electrical, or *thermal energy*, which reduces the power generated by solar collectors.

The effects of cloudiness on *industrial and civil engineering* are related to the worsening of natural illumination and changes in the thermal behaviour of buildings. The impact on *radio communication* is caused by changes in conditions for the propagation of electromagnetic waves.

The effects of cloudiness on human activities are illustrated by Photo 3.40.

3.12.1 Fog

Fog is an accumulation of small water drops or ice crystals within the near-surface layer of the atmosphere, reducing horizontal visibility to 1 km or less.

The *record frequency of fogs* is characteristic of the south coast of the Island of Newfoundland (Canada), where they are observed more than 120 days a year (Reference book of necessary knowledge 1994). The greatest centre of fog formation is the south-west territory of the Democratic Republic of the Congo, where an abundance of swamps, high air temperatures, and weak circulation within the near-surface atmosphere are conducive to the formation of fog (Mazur and Ivanov 2004). Average annual numbers of days with fog are shown in Fig. 3.17.

In essence, fogs are *clouds that are present near the Earth's surface*. As for every cloud, for fog formation, favourable conditions for the condensation of water vapour are necessary. Depending on the causes of fog formation, fogs are divided into two basic *classes* (Khromova and Petrosyants 2001): cooling fogs and steam fogs. Cooling fogs occur much more frequently.

Air cooling near the Earth's surface occurs in different *ways*: (1) when there is movement from a warm surface to a colder one, fogs formed by this process are called advective fogs; (2) in the course of radiative cooling of the Earth's surface and, accordingly, air, these fogs are called radiant fogs; and (3) under the

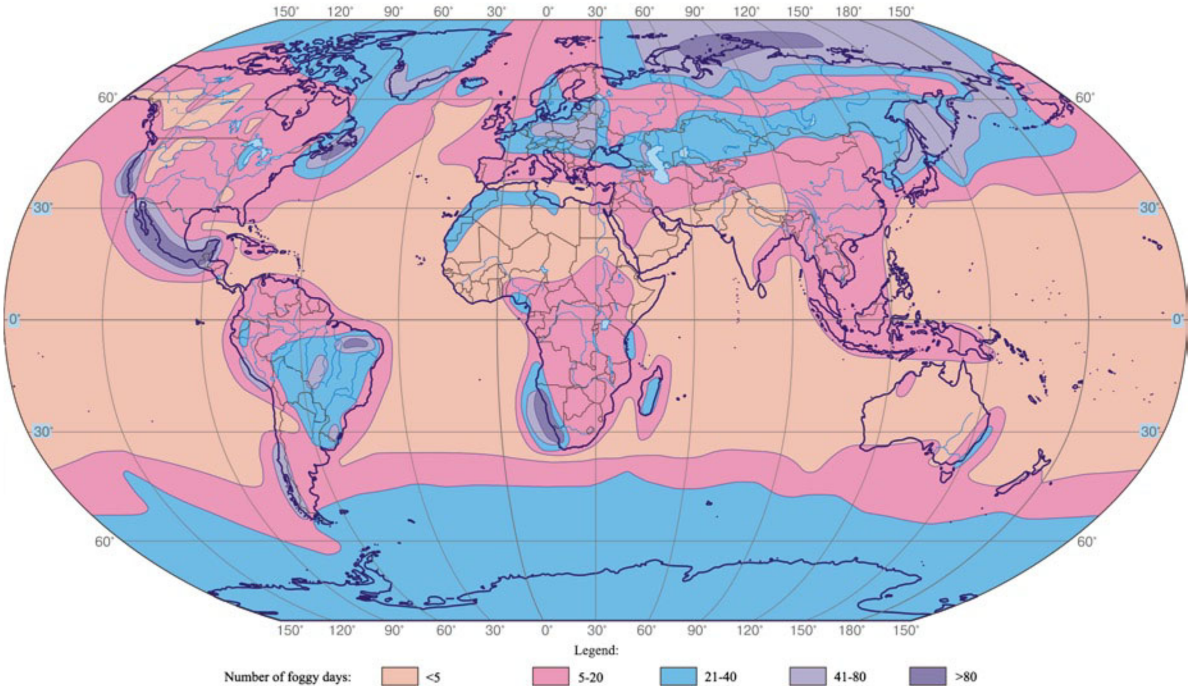

Fig. 3.17 Average annual number of days with fog (Khromov and Petrosyants 2001. Reproduced with permission of Moscow State University, Russia)

action of both processes, these are called advective–radiative fogs.

The water droplets in fog, as they also contain solid particles (dust), are most often electrically charged rather than neutral. In three cases out of four, the drops have like charges; however, they bear unlike charges in 25% of cases. On the whole, the *electrical properties of fogs* are similar to those of atomized clouds (Khromov and Petrosyants 2001).

Depending on temperature, fog, as for clouds, can be droplet, crystalline, or mixed. Fog consists *entirely of drops* at positive and small negative temperatures. At temperatures of −10°C and lower, ice crystals are added to the supercooled drops, and the fog becomes *mixed*. During heavy frosts, *ice fog* with visibility not exceeding several hundred metres can be formed (Kotlyakov 1994).

Fog influences the following *kinds of human activity*: (1) air transport, (2) water transport, (3) motor transport, (4) rail transport, (5) crop production, (6) recreational activities, (7) industrial and civil engineering, (8) solar power engineering, and (9) radio communication.

Fogs always constitute a threat to *aviation*. Even when modern devices are used for landing planes, fogs create difficulties. One example is a flight from Jakarta, Indonesia, to Sultan Mahmud Badaruddin II Airport, Palembang, Indonesia. On 24 September 1975, Flight 150 crashed on approach due to poor weather and fog just 4 km (2.5 miles) from the town of Palembang. The accident killed 24 out of 61 passengers and crew on board, and one additional person was killed on the ground.

On 10 April 2010, a Tu-154 aircraft crashed on approach in Smolenskaya oblast (Russia). Ninety-six passengers, including Polish President Lech Kachinsky and a number of high-ranking officials, were killed. Fogs inflict considerable economic damage to aviation when one is forced to *cancel* flights or to *change* flight paths.

Fogs have resulted in many *shipwrecks*. Due to low visibility, collisions of ships with each other, as well as with submerged and above-water reefs and icebergs, take place. Fogs are especially dangerous on the busy routes passing across the North Atlantic. For example, the collision with an iceberg and loss of the ocean liner *Titanic* were caused by heavy fog. At present, in order to avoid fogs in this area, the basic shipping lanes are shifted to the south during the winter (Weisberg 1980).

Photo 3.41 Per se, fog is a cloud located near the Earth's surface. Fogs pose ever-present threats to aviation, even given brand-new technical achievements. The photo shows the passenger terminal building at the airport in Hong Kong, immersed in a layer of dense fog. The upper photo shows the Hong Kong airport in fine weather. Fogs here are common in late winter and early spring when warm, humid air from the south-east meets cold waters near the coast of the South China Sea (Photo credit: Hong Kong Observatory of HKSAR, 17 January 2002)

The effects of fog on *motor* and *rail transport* are also caused by deterioration in visibility. Due to delayed detection of obstacles to traffic, numerous road accidents occur. The effects on *crop production, industrial and civil engineering*, *solar power engineering,* and *radio communication* are similar to those of cloudiness. The impacts on *recreational activities,* in addition to restriction of the use of ultraviolet radiation, are also related to a hampering of the enjoyment of scenery.

The influence of fogs on human activities is illustrated by Photo 3.41.

3.13 Humidity

Humidity is the content of water vapour in the air. The basic indicators used to describe it are absolute and relative humidity.

Absolute humidity reflects the water vapour content in the air. The *average annual value* for the whole Earth is 11 g/m^3. The absolute air humidity is closely related to temperature. For example, 1 cubic metre of air can contain 5 g of vapour at 0°C, while at 40°C, this value reaches 51°g (Vovchenko 1985). Generally, the absolute air humidity *decreases with latitude*.

Relative humidity indicates the degree to which the air is saturated with water vapour. This is the ratio between the amount of water vapour actually contained in the air and the maximum amount possible at a given air temperature. Relative humidity is expressed in percent and does not indicate the absolute *content of water vapour* in the air.

On the whole, the *annual variation* of relative humidity is opposite to variations in temperature; that is, the higher the temperature, the lower the humidity. The *diurnal variation* of relative humidity is in the opposite phase to the diurnal variation of temperature; therefore, a humidity minimum coincides with a temperature maximum and falls in the afternoon, while a diurnal humidity maximum corresponds to a temperature minimum and is observed at sunrise.

The diurnal range increases as we move away from the sea. In Dublin (Ireland), it is, on average, 7% in winter and 20% in summer; in Vienna (Austria), these values are 9% and 27%, respectively; and in Nukus (Uzbekistan), they are 25% and 45%, respectively. On clear days, variations in relative humidity are *greater* than those on cloudy days. For example, the amplitude on clear days in Vienna reached 20% in winter and 43% in summer (Khromov and Petrosyants 2001).

If the *water vapour* contained in the atmosphere were to be distributed on the Earth's surface in the form of moisture, then the water layer thickness would be 22 mm. The water vapour in the atmosphere is *renewed* 47 times a year; that is, every 7.8 days (Astapenko 1986). Of the total amount of atmospheric water vapour, 84% is provided by the hydrosphere, while 16% is supplied by evaporation from land (Troyan 1988).

Photo 3.42 Icing-up and hoar-frost formation greatly affect water transportation. Icing-up weighs down ships and puts them deeper into water. Consequently, the centre of gravity shifts upwards, making the ship unsteady. Yearly, 10 vessels are destroyed, and hundreds face high-risk situations owing to icing-up processes. The photo shows ice on the NOAA Ship *Miller Freeman* (Photo credit: U.S. National Oceanic and Atmospheric Administration)

Humidity has direct or indirect effects on a number of kinds of human activity, such as the *following*: (1) crop production, (2) livestock farming, (3) medical care, and (4) transmission lines.

Humidity is of great importance in *agriculture,* as it satisfies the need of plants for water. Many diseases and insect infestations of plants are directly related to humidity – many require high humidity.

The influence on *livestock farming* is that some animals feel best at low relative humidity (Betten 1985). Humidity is directly related to a number of diseases of livestock; some require high humidity, whereas others require low humidity.

One effect of humidity on *medical care* lies in the fact that increased air humidity results in a considerable increase in ether consumption, and, in this case, the anaesthesia proves to be more superficial. The moisture contained in the air impregnates the mask fabric. Because ether is lighter than water, it 'floats' and, to a considerable extent, is lost for aspiration. The increased delivery of ether may cause the water-soaked fabric of the mask to become icy. Inhalation of the cold air may result in post-operative complications (Assman 1966).

As for the effect of humidity on *transmission lines,* high humidity worsens the behaviour of insulators, which reduces the efficiency of electric power transmission. Humidity promotes *electrochemical corrosion,* causing metals to fail, and *microbiological corrosion* related to the activity of fungi and mould, causing considerable damage to organic materials (wood, leather, paper, rubber, plastics, textiles, etc.).

The *well-being of people* depends on humidity to a considerable extent. The hygienic standard for humans is relative humidity levels of 30–60%. An increase in humidity enhances the influence of both cold and hot weather. This has an adverse effect on people with kidney diseases and favours high blood pressure and the initiation of bronchial haemorrhages (Fedyunina 2004).

3.14 Glaze Ice

Glaze ice is a 'layer of compact ice accumulated on the ground surface and on objects due to freezing of supercooled drizzle droplets, raindrops or fog' (Glaciological encyclopaedia 1984, p. 104).

Glaze ice affects the following objects and *kinds of human activity*: (1) air transport, (2) water transport, (3) motor transport, (4) rail transport, (5) transmission and communication lines, (6) industrial and civil engineering, (7) forestry, and (8) livestock farming.

Ice-loading phenomena are very dangerous for *air transport*. In flights through clouds with supercooled

Photo 3.43 The danger of body icing to motor transport is less than that to ships. Nevertheless, glaze strongly complicates car operation. A car after an ice storm in the United States is shown (Photo credit: Pennsylvania Department of Conservation and Natural Resources, Forestry Archive, Bugwood.org)

drops, ice can accumulate on the propellers, front surface of the aircraft, back surface of wings and empennage group, wing flaps, and other structures. This accumulation results in increases in weight and head resistance and, as a consequence, loss of speed and altitude, as well as deterioration in aircraft sensitivity.

Statistics on air crashes show 51 incidents related to airframe icing, which have resulted in the deaths of 716 people. For example, on 31 October 1994, a flight from Indianapolis to Chicago encountered trouble. As a result of the aircraft entering an intensive icing zone, the controllability of the ailerons and wing flaps was dramatically degraded, which resulted in an accident. All 68 people on board were killed (http://en.wikipedia.org/wiki/American_Eagle_Flight_4184).

Ice deposits have a pronounced effect on *water transport*. Ships, like aircraft, are subject to icing, which not only reduces their operating efficiency but also may cause ships to be lost. Ice can form on the deck, masts and spars, rigging, frontal and side faces, and other structures. The ice deposits decrease the freeboard, and the ship's centre of buoyancy shifts upwards, which makes the ship *unstable*.

Ships can also be taken out of operation due to icing of *radio and radar aerials* (Encyclopaedia ocean-atmosphere 1983). The intensity of ice formation may be very high. For example, on 5 February 1996, the ice deposits on a medium trawler in the northern Sea of Japan reached 5.2 ton /h (Shelest 2003).

Smaller vessels with lower decks and superstructures suffer the greatest from icing. According to data of S.M. Myagkov (1995), about ten vessels are lost every year, and hundreds of them prove to be in hazardous situations. For example, four fishing seiners finding refuge in the port of Severo-Kurilsk (Russia) sank on 29 March 1966 due to a great amount of icing (Atlas of natural and technogeneous dangers and risks 2005).

The effects of glaze ice on *motor transport* are related to supercooled rain, which covers roadways with ice, making them very slippery and sometimes completely paralyzing traffic. In January 1998, for example, more than 2.6 million people – that is, 19% of the factory and office workers in Canada – encountered difficulties getting to their workplaces or could not come to work at all due to a storm with sleet (Bueckert 2004).

The impacts on *rail transport* are related to two factors: (1) icing of the railroad points, and (2) ice formation on the wires of the contact systems of electric trains. Icing of railroad points is one of the major causes of train delays. Ice

Photo 3.44 Ice-up destroys communication and power lines. The weight of ice crusts can reach 86 kg/m. The photo shows a telephone line covered with ice in the United States (Photo credit: U.S. National Oceanic and Atmospheric Administration)

formation on the wires of electric trains is accompanied with reductions in the voltage of train motors.

The impact of glaze ice on *transmission and communication lines* is very strong. The weight of glaze ice and rime deposits on wires may reach 86 kg/m; such loads are destructive for most transmission wires (Myagkov 1995).

Loadings that arise *under the combined influence of glaze ice and wind* (ice–wind loadings) are especially dangerous. In such cases, there is a synchronous increase of loading related to the ice mass and the force of the wind. A widely known example is the toppling of more than 1,000 transmission towers and about 30,000 wood poles after an ice storm in January 1998 in Canada.

Ice–wind loadings constitute a danger for a number of other industrial and civil structures: high-rise buildings, television relay towers, antenna posts, water towers, and others. During the period 1959–1997, about 140 events of the destruction of such structures due to *glaze ice* and wind were recorded in the United States (Mulherin 1998).

Glaze ice inflicts considerable damage to *forests*. The sleet on 4–10 January 1998 resulted in the loss of about five million sugar maple trees in central and eastern Canada. It is believed that 30–40 years will be needed to restore the production of maple syrup to its previous volume (Bueckert 2004).

The effects of glaze ice on *livestock farming* are related to the fall of supercooled rain. The ice crusts formed destroy grasses by compressing them and reducing the availability of oxygen, causing a fodder shortage for grazing animals (Meadow cultivation 1990).

The effects of glaze ice on human activities are illustrated by Photos 3.42–3.45.

Photo 3.45 Glaze ice has strong negative consequences for horticulture and forestry. The photo shows a ripe crab apple covered in icy glaze due to freezing rain (Photo credit: http://en.wikipedia.org/wiki/Winter_storm)

3.15 Ice-Covered Ground

Ice-covered ground occurs when an 'ice crust on the ground surface … forms after a thaw or rain as a result of fall of temperature as well as due to freezing of sleet, rain or drizzle from the contact with strongly cooled ground surface' (Glaciological encyclopaedia 1984, p. 104).

The *differences* between *glaze ice* and *ice-covered ground* are as follows. The *second phenomenon* is characteristic only of the ground surface, whereas the *first* is peculiar predominantly to objects above the ground, such as branches of trees, wires, and parts of planes and ships. In case of spatial overlapping, attention should be paid to the temperature of the rain, drizzle, or fog droplets. In the case of *glaze ice*, they, being supercooled, freeze on the ground surface and objects. For *ice-covered* ground, however, the accumulated water freezes without the immediate fall of supercooled precipitation (Glaciological encyclopaedia 1984).

Ice-covered ground primarily *affects* motor and air transport, livestock farming, and crop production.

The impact on *motor transport* is similar to that of glaze ice, because the mechanism forming the ice crust on the road surface is of no practical importance. On the whole, the freezing of surface water after a thaw

Photo 3.46 The effects of atmospheric ice and glazed frost on motor transport are identical, as the mechanism of ice crust formation on the roadway surface is of no critical importance. On the whole, the freezing of water on the ground after snow occurs much more often; therefore, glazed frost is more dangerous from the viewpoint of influence on motor transport. It increases the slipperiness of a roadway, resulting in a sharp increase (three times) in the number of motor car accidents. A glazed frost in North Carolina (United States) is shown (Photo credit: University Corporation for Atmospheric Research, United States)

occurs much more often than the fall of supercooled precipitation; therefore, from the viewpoint of the impact on motor transport (as well as on crop production and livestock farming), *ice-covered ground* is more important. An increase in the slipperiness of road surfaces triples the number of accidents (Myagkov 1995).

The mechanism of influence on *aviation* is identical, in the case of landing strip *icing*. A McDonnell Douglas DC-10–30 airplane flying from Newark International Airport to Logan International Airport in Boston, Massachusetts, on 23 January 1982 touched down 850 m beyond the displaced threshold (the beginning portion of a runway, which is not used for landings). Under normal circumstances, such an incident would have been of minor importance, and the plane would have had sufficient space to come to a full stop on the 3,000-m-long runway. However, the runway was covered in ice, and the braking action was poor to nil. The plane then skidded across a field and a taxiway before coming to rest in the −1°C (30°F) waters of Boston Harbor (Betten 1985).

The formation of an ice crust due to rain falling on a cooled ground surface or water freezing after a thaw is very dangerous for *grazing animals*. For example, early in the 1980s, ice-covered ground on Chukotka (Russia) caused mass mortality of domesticated deer due to fodder shortage (Myagkov 1995). Ice-covered ground also affects *wild animals*. In addition to the adverse effects related to restrictions in the availability of fodder, *positive effects* are also possible. Increases in the snow-bearing capacity owing to the thin crust of ice over the snow facilitates the travel of wild animals.

Ice-covered ground exerts pronounced effects on *crop production*. The ice crusts formed after thaws or after rainfall with subsequent freezing have thicknesses of 20–50 mm, and they sometimes reach 150 mm. They are lapped (adfreezed to the ground) and suspended. For plants, the lapped crusts are hazardous because sometimes they inflict mechanical damage as well as contribute to heaving and winter-killing. One more negative consequence of ice crusts is a sharp rise in concentrations of carbonic acid emitted by plants during photosynthesis (Chirkov 1988).

The effects of ice-covered ground on human activities are illustrated by Photo 3.46.

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4 Hydrological Processes

Abstract

Hydrology is the science that examines natural waters, and the phenomena and processes that occur in them. In principle, it is impossible for some natural processes to proceed without the participation of water. In this book, those processes in which water is especially important are categorized as hydrological processes. Among them are the following: (1) processes that take place directly in the water column, within the ordinary boundaries of water bodies (currents, upwelling, internal waves, seiches, etc.); (2) processes in which the major effects are related to the spreading of water from the ordinary confines of a water body to territories adjacent to it (river floods, wind-induced surges, changes in the levels of closed lakes, tides); and (3) processes that occur on the surfaces of land or water, primarily related to water in the solid state (icebergs, sea or river ices, glaciers, ice jams, etc.). Many of the listed processes can not be completely attributed to any one of the listed categories (for example, wind-generated waves influence human activities within the ordinary confines of water bodies as well as when they spread to land). Nonetheless, in spite of some conditionality, consideration of the category of hydrological processes is worthwhile.

4.1 River Floods

A *flood* is the inundation of a locality as a result of rising water levels in a river, lake, or sea. River floods are characteristic of all continents except Antarctica, and their yearly number reaches approximately 10,000 (Course of lectures on general and ecological chemistry 1993).

According to data of A.B. Avakyan and M.N. Istomina (2002), about *one billion people* reside on periodically flooded territories, while the *land area* affected by floods is about *three million square kilometres* on the Earth, including 600,000 km^2 in China; 400,000 km^2 in Russia; 300,000 km^2 in Brazil; 280,000 km^2 in the United States; and 250,000 km^2 in India. China suffers from river floods to the *greatest extent*; they killed five million people in China during the period of 1860–1960 (Smith 1992). Physical exposure and relative vulnerability to floods are shown in Fig. 4.1.

The following *causes* of floods have been identified: (1) melting of snow; (2) abundant rainfall; (3) joint action of melting of snow and rainfall; (4) breaches of rock-dammed lakes; (5) failure of dams; (6) ablation due to different reasons (sudden warming, volcanic eruptions, etc.); (7) wind-induced setups in river mouths; (8) spring ice jams; and (9) autumn ice jams (hanging dams).

Flood damage is determined by the following *parameters* (Mandych 2003): (1) flooding depth (the higher the water level, the greater the number of damaged

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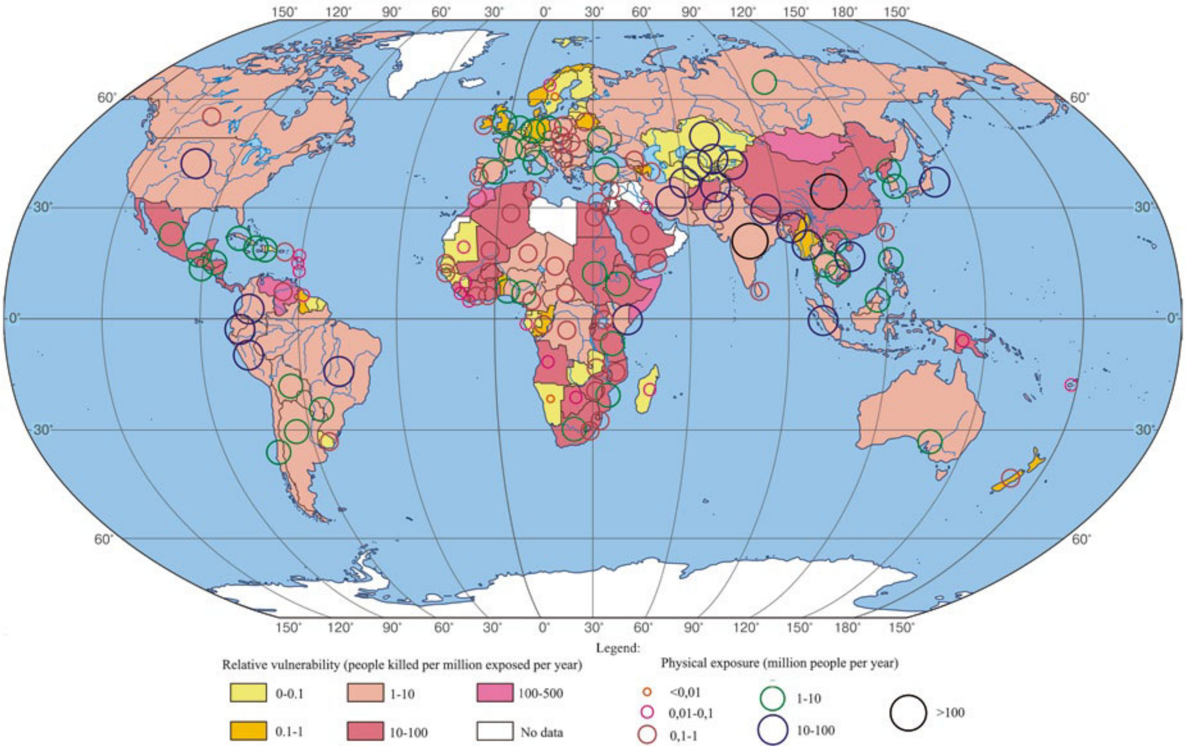

Fig. 4.1 Physical exposure and relative vulnerability to floods, 1980–2000 (Reproduced with permission of United Nations Development Program)

structures, property, etc.); (2) flow velocity, which affects the carrying and eroding capacities of the watercourse; (3) thickness of loose deposits remaining beyond the limits of the riverbed after the water recedes (expenses for their removal can form a considerable part of losses related to floods); and (4) water rise rate (the slower the rise in water levels, the greater the possibilities for protection of property and populations).

River floods affect most economic entities and *kinds of human activity*. Among the most vulnerable are (1) industrial and civil engineering; (2) crop production; (3) livestock farming; (4) transport; (5) bridges; (6) aquaculture; (7) fisheries; and (8) forestry.

The effects of river floods on *industrial* and *civil engineering* include the following (Safety of ability to live 1995): (1) demolition and damage of buildings, structures, and engineering services, as well as of equipment; (2) interruption of work in enterprises; (3) deterioration and loss of finished products and partly completed articles in the warehouses of enterprises; and (4) fires and explosions.

Buildings are damaged and destroyed in a number of *ways*. They *are swept away* by the flow as a result of the considerable water pressure. In the event that the dynamic pressure is insufficient to completely destroy a building, the action of flowing water causes a continuous deepening of cavities and *scouring of foundations*. In brick buildings, the *destruction of the brick masonry* with loss of bricks is observed. In concrete structures, the *corrosion of reinforcement* occurs. Wooden structures are *damaged by decay,* and the *plaster* peels off. The activation of a number of unfavourable geological processes due to floods – especially subsidence, swelling, and cryogenic swelling (see Sects. 1.2.1, 1.7, and 1.8) – contributes to the demolition and damage of buildings. *Damage to engineering services* (water, gas and sewer pipes, electric, television, telephone, and telegraph cables, etc.) are generally caused by uneven settling (Accidents and catastrophes 1995).

Damage caused by *deterioration and loss of products* occurs due to combined factors. A *part* of the products is swept away by water or becomes useless. The *second* part deteriorates to a lesser extent and can be sold at reduced prices. The *third* part of the products can be completely restored; however, it is in need of drying,

Photo 4.1 Inundation of dwellings and industrial structures during river floods is widespread. Approximately one billion people inhabit areas subjected to periodic inundation. The photo shows a flood in a neighbourhood in south-west Iowa (United States) (Photo credit: Keith McCall, USDA Natural Resources Conservation Service, 1999)

sorting, cleaning, and other attention, which requires some expense.

Fires and explosions during floods are not rare. In the past, they generally arose due to firing stoves, while now, they occur due to breakdowns and short circuits of electric cables and wires.

The effects of floods on *crop production* include the *following*: (1) failure of crops; (2) losses of cereal resources and seeds; (3) decay of fertilizers, herbicides, pesticides, and other chemicals; (4) washout of the fertile soil layer; (5) soil drift with sand and silt; (6) over-consolidation of soils; (7) losses of croplands due to crushing of shores, landslides, rockfalls, and other events; and (8) destruction of the agricultural infrastructure.

The *failure of crops* can take place as a result of inundation and under-flooding of crops and unharvested yield. In the case of inundation, the damage depends on the kind of crop, and the depth, time (season), duration, flow velocity, and other parameters of the flood. As a whole, it abruptly increases at the inundation depth of more than 0.4–0.5 m. During under-flooding, the damage to the crops is determined by over-wetting of the root layer.

The *economic damage to crops* is based on the cost of the work performed (ploughing, harrowing, sowing, water application, fertilizer application, pest control, post-irrigation cultivation, packing, etc.), material costs (costs of seed, fertilizers, herbicides, pesticides, and other chemicals), and the loss of expected profits. If the permanent crops perish, such as in the case of flooded berry fields, gardens, and vineyards, the expenses increase because of the greater time necessary to restore the crops.

The intensity of *the washout of the fertile soil layer* is determined by the flow velocity of the flood, soil type, character of crops, and other factors. The re-establishment of fertility takes time and funds for land treatment and application of organic and mineral fertilizers. The *drift of soil with sand* also reduces the soil fertility, which requires the implementation of appropriate measures.

In a number of cases, floods and immersion in standing water result in *over-consolidation of soils*. In order to make these lands useful for farm production again, subsoiling or ploughing with application of fertilizers is needed. The typical consequences of river floods are failure of shores and landslides, which, in a number of cases, reduce *the areas* of land that are useful for agriculture. Damage and *destruction of different agricultural objects* (greenhouses, irrigation and drainage structures, and other infrastructure) are also characteristic.

Among the floods causing maximum damage to crop production is a flood in Bangladesh in July–August 1974. In this flood, 80% of the summer yield and part of the basic winter crops were destroyed, which together amounted to 40% of the annual production of the country (Davis 1997, vol 2).

The effects of floods on *livestock farming* include the *following*: (1) loss of livestock; (2) damage to

Photo 4.2 The impacts of floods on plant cultivation are diverse. Most frequently, agricultural lands are inundated or waterlogged. Depending on the duration of a flood, it leads either to crop losses or to utter death of plants and crops. The photo shows flooded cropland in south-west Iowa (United States) (Photo credit: Keith McCall, USDA Natural Resources Conservation Service, 1999)

fodder and grass yield; (3) destruction and deterioration of stored fodders; (4) silting of hay fields and pastures; and (5) demolition of stock-raising farms. The mechanisms of action are similar to the impacts on crop production. A significant difference is only in the additional expenses for burial of killed livestock, which can be considerable. For example, during the flood of 1988 in India, 172 million heads of livestock were killed (Yasamanov 2003).

Floods affect all kinds (modes) of *transport*, in the following *ways* (Alekseev 1988; Accidents and catastrophes 1995): (1) destruction of bodies and coverings of motor roads, railroads, and airfields; (2) destruction and damage of transport vehicles; (3) road-traffic disturbances; (4) stoppage of river transport operations; and (5) damage to pipelines. The influence on *road beds* and *coverings* can be caused by the dynamic water impact, resulting in the formation of breaches in the road bodies or in their demolition. For example, during the flood in May 1982 in south-eastern China, 35 km of the Guangzhou–Beijing railway line were entirely swept away (Davis 1997, vol 2).

Destruction and damage to transport vehicles predominantly affect *motor transport*; however, damage to railway cars, locomotives, and even aircraft and ships during floods is not infrequent. The effects on road traffic depend on the depth of the water. *River transport* is strongly affected by floods. Ferrying across flooded rivers is nearly completely stopped. The effects on *pipelines* are mainly related to the dynamic water impact and differential settlement of ground in the case of pipelines on the surface, and washing-out of subsurface pipelines.

The demolition and damage of *bridges* are typical consequences of river floods, caused by direct water pressure on bridge spans and footings and as a result of the intensification of scour at the footings, especially those earlier positioned on the shore. In November 1988, a flood in Thailand damaged or swept away about 300 bridges (Hydrometeorological dangers 2001).

The effects on *fisheries* and *aquaculture* are characteristic. Floating garbage renders fishing with nets and seines impossible. Aquaculture ponds, fish hatcheries, and other aquaculture enterprises located in flood plains are damaged or demolished. For example, in November 1988, the flood in Thailand destroyed more than 1,000 farms for the culture of freshwater shrimp (Davis 1997, vol 2).

The influence on *forestry* is related to the destruction and slowdown of the productivity of forests as well as to the washing down of procured lumber. The extent of damage is, to a considerable degree, determined by the duration of the flood. Different tree species are characterized by different survival times under water (hydroperiods; 3–5 to 60–90 days).

Photo 4.3 Nevertheless, if water depths exceed a certain threshold, car traffic stops and earthworks and roadbeds are damaged. The photo shows the Missouri River flooding in the vicinity of Cedar City and Jefferson City Memorial Airport, Missouri (United States) (Photo credit: Missouri Department of Transportation, 30 July 1993)

Photo 4.4 Cars are often inundated during river floods. Usually, restoring a car after a flood is very costly and therefore hardly expedient, since a damaged car needs replacement of electric devices and cleansing of all its structures and mechanisms of all-pervasive silt particles. The photo shows a car after a flood in New Zealand (Photo credit: Ilan Kelman (http://www.ilankelman.org), March 2004)

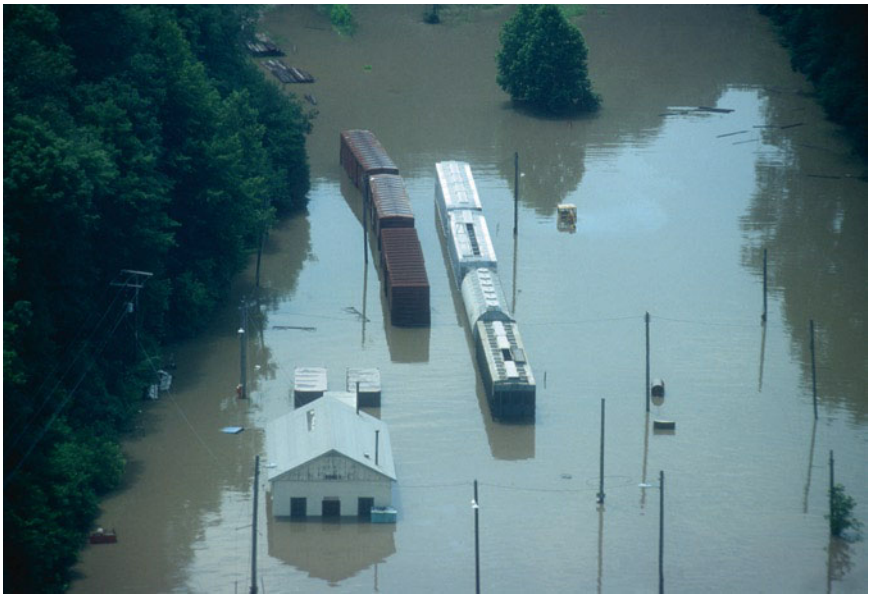

Photo 4.5 Railway transportation also suffers from floods, though to a lesser extent. The flood of 1993 on the Mississippi River was caused by a combination of copious spring snow melt and torrents in the beginning of summer. It caused $15 billion in property damage. The photo shows an inundated railway line, a station, and rolling stock in a river valley (Photo credit: U.S. University Corporation for Atmospheric Research, July 1993)

Annual average losses from river floods are US$20–25 billion, while the *annual average mortality* reaches 10,000 people (Govorushko 2007a).

The effects of river floods on human activities are illustrated by Photos 4.1–4.5.

4.2 Wind-Induced Surges (Coastal Floods)

A *wind-induced surge* is a water level rise that occurs as a result of the force of wind on the water surface. In most cases, the origin of wind-induced surges is related to the passage of tropical or extratropical cyclones.

Surges occur most frequently on the lowland coasts of the United States, Mexico, Bangladesh, Japan, the Philippines, Australia, the Netherlands, Belgium, Great Britain, Italy, Portugal, Poland, and the Federal Republic of Germany. Areas of wind-induced surges are shown in Fig. 4.2. Coastal floods are also observed on the shores of large lakes (for example, the Great Lakes, Caspian Sea) and storage reservoirs.

Wind-induced surges arise on the windward shores of water bodies due to *tangential stress* on the water-air interface. The wind involves the water layers, which experience only resistance of underlying water layers in motion towards the windward shore. With the creation of the water surface slope, the lower layers begin to move by gravity in the opposite direction; however, they should overcome the resistance of the bottom roughness, which is higher than the friction forces between water layers. The inequality of flows of water moving in the opposite directions results in a water level rise near the windward shore and a water level fall near the lee shore (Nezhikhovsky 1988).

The *rate of water rise* during wind-induced surges depends on the following *factors*: (1) wind force and direction; (2) slope of the bottom (the more gentle the slope, the higher the rise); (3) coastal configuration (the rise is maximal in open, elongated bays); and (4) timing in relation to tidal cycles (the greatest rise is observed when the wind-induced surges coincide with the astronomical tide). The areas of lands flooded during wind-induced surges reach thousands of square kilometres.

The *extent of damage* from coastal floods depends generally on the following *factors*: (1) value of maximal water rise; (2) duration of flooding (the longer the flooding, the greater the damage); (3) rate of water level rise (if the water level rises slowly, protective

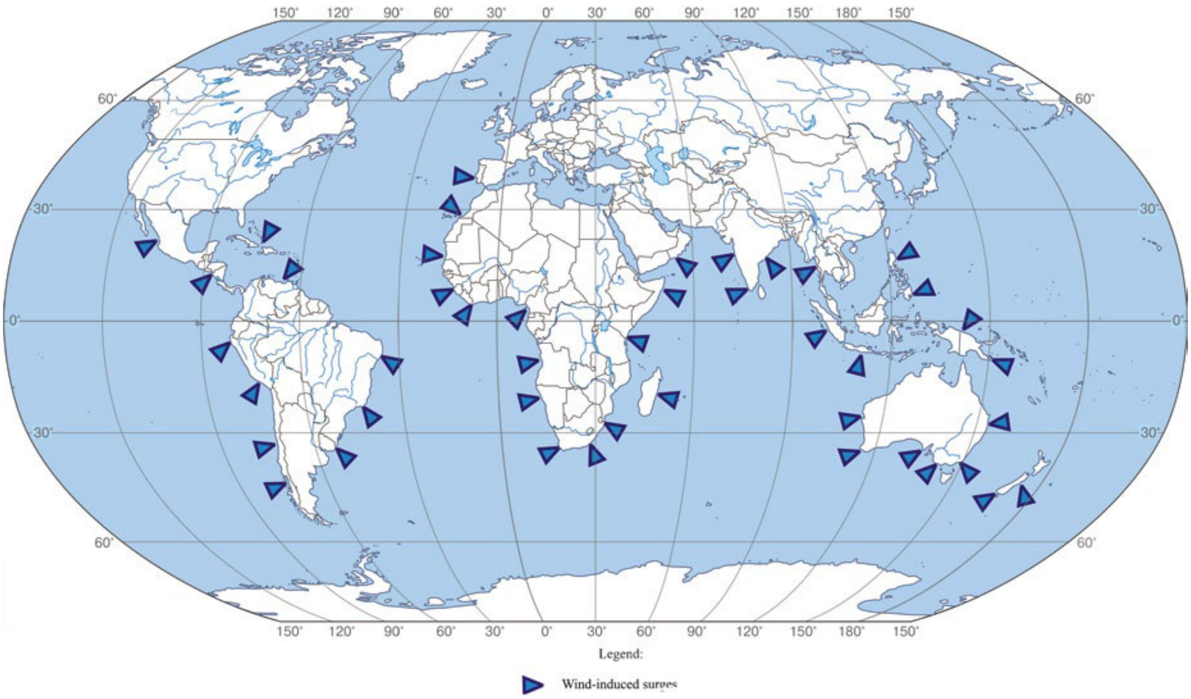

Fig. 4.2 Areas of wind-induced surges (Adapted from Atlas of the world 1999; Atlas of natural and technogeneous dangers 2005)

measures are possible); (4) how often they occur (repeated level rises cause lesser consequences); and (5) timing of the flood (for example, before or after harvesting).

Coastal floods result in considerable mortality and affect the following objects and *kinds of human activity*: (1) industrial and civil engineering; (2) crop production; (3) livestock farming; (4) motor transport; (5) rail transport; (6) water transport; and (7) military activities.

It is believed that the *death toll* of coastal floods during the period for which records have been kept exceeds one million people (Kukal 1985). The greatest death toll was recorded during the flood on 13 November 1970 in East Pakistan (now Bangladesh). As a result of a cyclone over the Bay of Bengal, the sea level rose by 3 m, which flooded a densely settled territory of 7,500 km^2; according to different sources, the death toll reached 300,000–700,000 people. Among the *major disasters* of this type are also the wind-induced surges in Zuider Zee Bay in the Netherlands on 17 November 1218 and on 19 November 1421. Each event killed about 100,000 people (Gill 1986, vol 2). According to our data, the annual average *mortality* related to wind-induced surges is 4,000–5,000 people, while the *economic losses* reach US$5–6 billion (Govorushko 2007a).

The effects on *industrial and civil engineering* are, in many respects, similar to those for river floods. *Differences* in the effects are generally as *follows*: (1) greater corrosion of metal structures and reinforcement in reinforced concrete structures due to water salinity; (2) lesser rates of scouring of foundations by virtue of lower grades and, as a consequence, lower speeds of water motion; and (3) greater damage from fires due to the higher seawater conductivity.

Among the most striking *instances* of effects on industrial and civil engineering is the flood in June 1991 in Bangladesh, when a tenth of the country's population was made homeless (Myagkov 1995). As a result of a flood on 17 February 1962, about 500,000 people on the North Sea coast in Germany were made homeless (Davis 1997, vol 2). On the whole, the effects of surges on industrial and civil engineering are on a *smaller scale* than those of river floods, due to the relatively short periods of wind-induced surges.

Photo 4.6 The impacts of wind-induced surges on dwellings and industrial structures are similar to those of river floods. These two figures show the same site on the coast in Alabama (United States) before and after the sea flood caused by Hurricane Ivan in September 2004. The five-storey building in the middle of both shots was destroyed when the foundation washed away (Photo credit: U.S. Geological Survey, 17 July 2001 and 17 September 2004)

The impacts on *crop production* during coastal floods are the same as those during river floods, except for the following *differences*: (1) there is essentially no loss of croplands due to collapse of shores, landslides, etc.; (2) covering of soil with sand, silt, etc., occurs on a smaller scale; and (3) there is much more intense destruction of crops and withdrawal of agricultural land from production due to water salinity. The greatest effect on crop production was recorded during a flood on 1 February 1953 in the Netherlands, when 9% of the arable land of the country (1,500 km^2) was withdrawn from production (Smith 1992).

Two of five impacts of coastal floods on *livestock farming* (destruction of the feed crop yield and decay of procured forage) occur to a greater degree than with river floods. One impact (silting of hay fields and pastures) occurs to a lesser extent, and two impacts (loss of cattle and destruction of stock-raising farms) occur to a degree comparable with those that occur with river floods. The *greatest economic damage* is caused by loss of cattle, especially considering the expensive burial of dead animals. During a flood on 25 May 1985 in Bangladesh, about 500,000 head of cattle drowned (Davis 1997).

Photo 4.7 These two photos illustrate the effects of dynamic impacts of water. Several houses in Alabama (United States) showed in the lower photo were destroyed by water pressure during a storm surge generated by Hurricane Ivan. The constructions with pile foundations proved to be steadier. However, they too were seriously damaged when the ground was washed out of the piles (Photo credit: U.S. Geological Survey, 17 July 2001 and 17 September 2004)

The effects on *transport* are also similar to the influence of river floods, except that sea vessels are affected. During a storm surge in November 1839, the Indian city of Coringa, located at the mouth of the Ganges River, was completely destroyed, and about 20,000 vessels were demolished (Davis 1997, vol 2). In November 1995, a coastal flood submerged the Sakhalin port of Moskalvo (Russia) (Atlas of the Sakhalin coastline 2002). The effects on *military activities* are related to problems with the landing of troops.

The influence of coastal floods on human activities is illustrated by Photos 4.6 –4.8.

Photo 4.8 Wind-induced surges are typical of Venice, Italy. The photo shows a house door with an additional hermetic barrier, which protects the house from seawater (Photo credit: Lee Bosher, Loughborough University, United Kingdom, August 2003)

4.3 Sea Currents

Sea currents are the progressive motion of water masses in the oceans and seas caused by different forces. The distribution of currents in the world's oceans is illustrated in Fig. 4.3.

Currents are subdivided based on lifetime into *constant* currents (changes in direction do not exceed 90°) and *shifting* currents (reverse in direction). Most currents are of a constant nature. As for the *physical properties*, warm, cold, and neutral currents have been identified. The temperature difference in a current as compared with the adjacent water can not be large; however, it is sometimes quite important. For example, in April, the temperature in the central Gulf Stream at the Arctic circle is 20°C, while within several hundred kilometres to the west, it is somewhat higher than 0°C, and the polar ice edge is farther west (Astapenko 1986).

The *initiation of sea currents* can be caused by wind friction against the ocean surface (drift and wind-driven currents), non-uniform distribution of water temperature and salinity (density currents), an incline of the water from the horizontal (discharge, gradient, and compensation currents), and other reasons. Currents caused by only some of the mentioned factors are *rare*. For example, the Gulf Stream is simultaneously a density, wind-driven, and discharge current (Climatology 1989), and roughly 50% of the water is moved by wind action (Encyclopaedia ocean-atmosphere 1983).

Friction acts in currents of every type. The air does not just slide along the water surface, but due to friction (tangent wind action), it entrains the surface layer. The depth of the friction layer depends on a number of factors. For example, at latitudes of 50°N and 50°S, it is about 60 m at a wind velocity of 7 m/s. The maximum thickness of the water layer directly affected by the wind is roughly 100 m (Encyclopaedia ocean-atmosphere 1983). The *speed* of the surface current is approximately 1–3% of the wind velocity (Harvey 1982).

The *non-uniform distribution of temperature and salinity* in an ocean current is caused by differences in water density. Other things being equal, cold, dense water moves toward warm and less dense water and is submerged gradually. The non-uniform distribution of salinity also results in displacement of saltier water to the less salty (and denser) liquid.

Differences in levels between different areas of water can be caused by the following *factors*: (1) surging caused by wind action; (2) variations in atmospheric pressure; (3) river run-off increasing water levels near the shores; and (4) non-uniform distribution of precipitation and evaporation zones. On the whole, the role of these factors in initiating sea currents is minor.

The *major elements* of a current are direction, stability, and velocity. The method of determining the direction of currents is *different* from the method used to determine *wind direction*. In the case of a current, it is defined by the direction to which the water flows

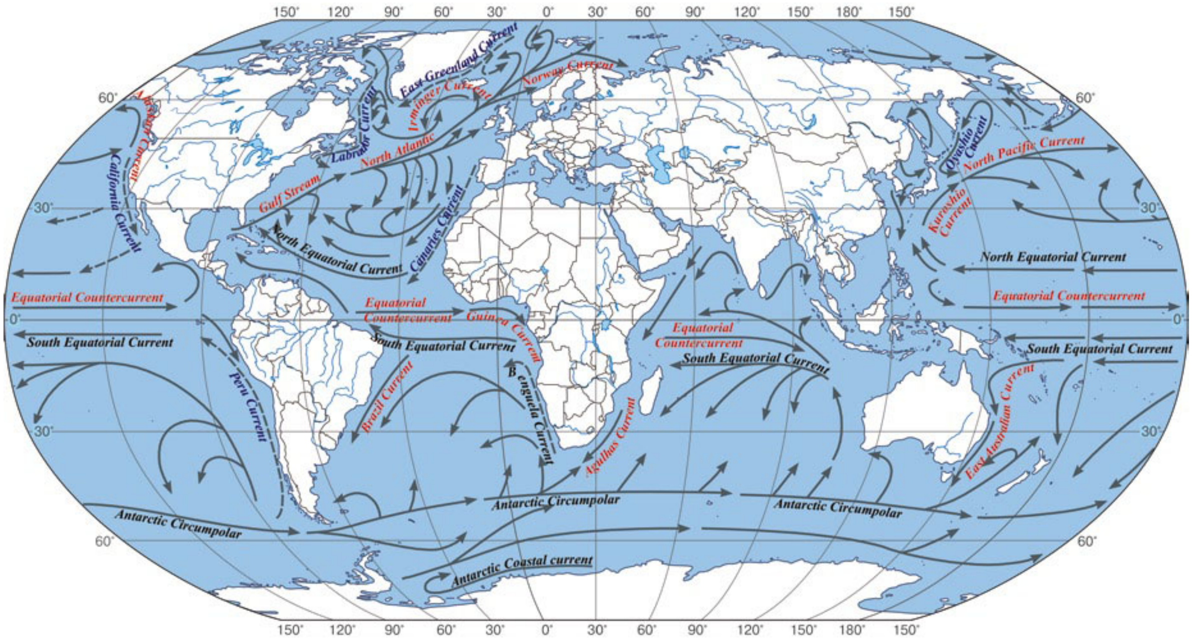

Fig. 4.3 Scheme of oceanic currents (Adapted from Tolmazin 1976; Zalogin and Kuzminskaya 2001). Warm currents are in *red*, cool currents are in *blue*

(for example, a north-western current moves to the north-west). Wind direction is defined by the direction from which the wind blows; that is, an east wind blows from the east (but the air moves in a westerly direction).

Current velocities are quite different. The *average velocity* of the world ocean surface water circulation is estimated at about 10 cm/s; that is, only 0.36 km/h (Burkov 1980). The *maximal values* are many times higher, however. For example, they reach 3 m/s in the Gulf Stream and 3.5 m/s in the Somali Current (Bogdanov 1994).

Sea currents have a pronounced effect on water transport. In addition, they affect military activities, fisheries, and the mineral resource industry.

The effects of sea currents on *sea transport* can be both negative and positive. The *negative effects* are that they decrease the speeds of ships and cause difficulties in navigation. The *positive effect* is that they can increase the velocity of a ship when the ship's heading coincides with the current direction. At present, data on sea currents are used by ship navigators in order to choose optimal routes and to determine drift corrections (i.e. difference between the true position of a ship and the position where it should be).

A certain positive importance of sea currents that has been lost now is in the delivery of *bottle mail*. Using bottle mail, seafarers have quite often informed others of the loss of their ship. This kind of communication was considered to be so important that, in England, there was a position in the Admiralty devoted to opening bottle mail.

The effects on *military activities* concern navy vessels. The influence on *naval surface ships* is the same as that on other surface water transport. As for *submarines*, in addition to the effect on the velocity of a vessel, the problem of determining location is of major importance. In many cases, submariners are unable to use astronomical objects to determine coordinates and have to use data on submarine drift caused by deep-water currents.

The effects on *fisheries* are related to the fact that near the boundary of cold and warm currents and where the current and countercurrent are found side by side, there is a rapid development of plankton and *mass fattening of fish*. One more factor of influence on fisheries is the fact that temperature differences result in a *variety of development cycles* of plankton. Neighbouring plankton populations are simultaneously in states of different 'biological seasons'. This alone provides stable

Photo 4.9 These two photos (4.9 & 4.10) demonstrate how sea currents have impacts on climate and, indirectly, on human activities. First photo was taken in summertime at latitude 70°N in Nansen Fjord, Greenland, in 1996 (Photo credit: Morten Hald)

Photo 4.10 Second photo also was taken in summertime at latitude 70°N in Tromso, Norway, in 2001. So pronounced climatic distinctions result from the impacts of the cold East Greenland Current and the warm Gulf Stream (Photo credit: Morten Hald)

forage resources for herring in the Norwegian and Greenland Seas (Aizatulin et al. 1984).

The influence on the *mineral resource industry* is related to oil and gas extraction from the seabed. When wells are drilled in deep-water areas, specially equipped anchored vessels are used. Information on currents is needed not only to calculate accurate vessel positions, but also to predict the travel of oil patches under emergency conditions such as an oil spill.

The effects of sea currents on human activities are illustrated by Photos 4.9 and 4.10.

4.3.1 El Niño and La Niña

El Niño is defined in different ways. In a restricted sense, it is a 'warm seasonal surface current in the Pacific Ocean along the shores of Ecuador and Peru within the belt between the equator and 5–7°S′ (Geographical encyclopaedic dictionary 1988, p. 563). *In a more comprehensive sense*, El Niño is a phenomenon of periodical, more distant penetration (to 15°S) of warm waters (so-called Southern Oscillation). The use of this term in a more comprehensive sense is more widely accepted.

The *La Niña* is a phenomenon that is opposite to the El Niño Southern Oscillation phenomenon. During La Niña, cooler waters are distributed a distance of 5,000 km (from Ecuador to the Samoa Islands), whereas during El Niño a belt of warm waters is present.

At the *heart* of the El Niño phenomenon is an interaction between the atmosphere and the ocean. In ordinary years, the trade winds drive the upper warm layers of water to the western Pacific Ocean, causing the sea surface near Indonesia's shores to become about 0.5 m higher than that off the shore of Ecuador.

When the surface waters leave the shores of South America, they are substituted for the colder waters rising from depths of 100–300 m and containing large quantities of nitrogen and phosphorus. When the waters rich in organogenic materials are in the illuminated zone, rapid development of phytoplankton occurs. In turn, algae serve as food for zooplankton, which grow abundantly and are forage for numerous fish, especially anchovies. This area is considered to be *most productive in the world*.

In ordinary years, ocean surface temperatures along the whole Pacific coast of South America vary in the range of 15–19°C, which are about 8°C lower than those off the shore of Indonesia. The origin of El Niño is related to the *pressure redistribution* over the Indian and Pacific Oceans, which results in weakening and even changes in the direction of the trade winds of the southern hemisphere (Allaby 1996).

The heated water (the area of a tongue of waters with elevated temperatures corresponds roughly to the area of the United States) shifts to the east in the form of a slow wave. The temperatures of surface water off the shore of South America increase by 6–10°C. These waters, which are characterized by a much lower density, *slow down the water rise* and, accordingly, the arrival of *biogenic elements*. As a result, phytoplankton productivity decreases abruptly, which in turn adversely affects all the living organisms at the higher levels of the marine food chain.

The *periodicity* of El Niño is 2 –7 years. The question of the causes of its origin is still not settled. The *duration* of El Niño varies from 3 to 22 months. During the period 1948–1997, it lasted, on average, 9.54 months (Petrosyants and Gushchina 2002).

The *effects* of El Niño on human activities may be direct and indirect; it is very difficult to distinguish between the two. The *effects* on fisheries, sea transport, livestock farming, and the mineral resource industry can be described as *conditionally direct*. The *indirect effects* are extremely varied and become apparent through other natural components, especially climate. Anomalies during El Niño and La Niña are shown in Figs. 4.4 and 4.5.

The influence on *fisheries* is related to the physical and biological variations in the ocean, which determine the populations and areas of fish distribution. The effect on the *anchovy* population is major. Anchovies comprise 5.5% of the world catch of fish (Allaby 1996). In 1970, Peru had the greatest catch of fish in the world because of anchovies: the catch at that time reached 12 million tons. After the 1972–1973 El Niño, the catch of anchovies in this country dropped to 1.8 million tons, which caused an economic catastrophe (Aizatulin et al. 1984).

In contrast to anchovies, other fish species do not perish but rather *migrate* to the north and south in search of cooler waters and food. Some species do not leave their habitat area but instead move to the deeper layers of the ocean, becoming inaccessible to trawlers. El Niño has the greatest impacts on the distributions of the *sardine*, *jack mackerel*, and *mackerel* populations (Impacts of El Niño on fish distribution 2004).

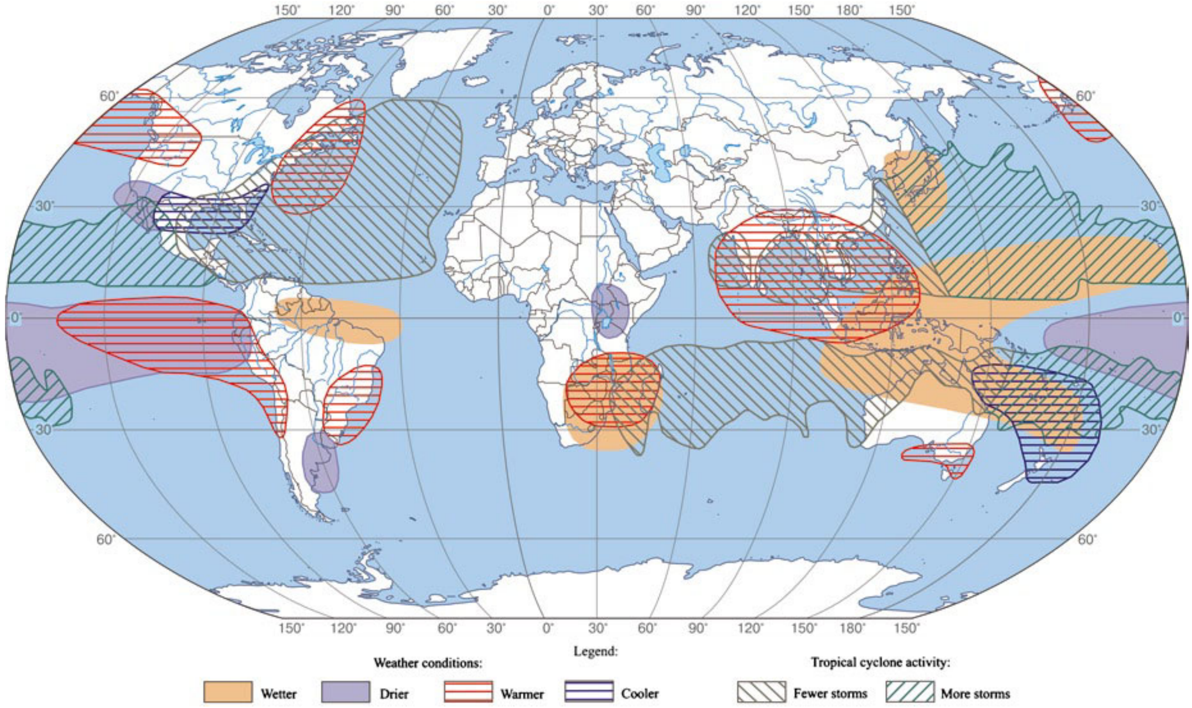

Fig. 4.4 Anomalies during El Niño (World map of natural hazards 2009. Reproduced with permission of Munich Re-Geospatial Solutions)

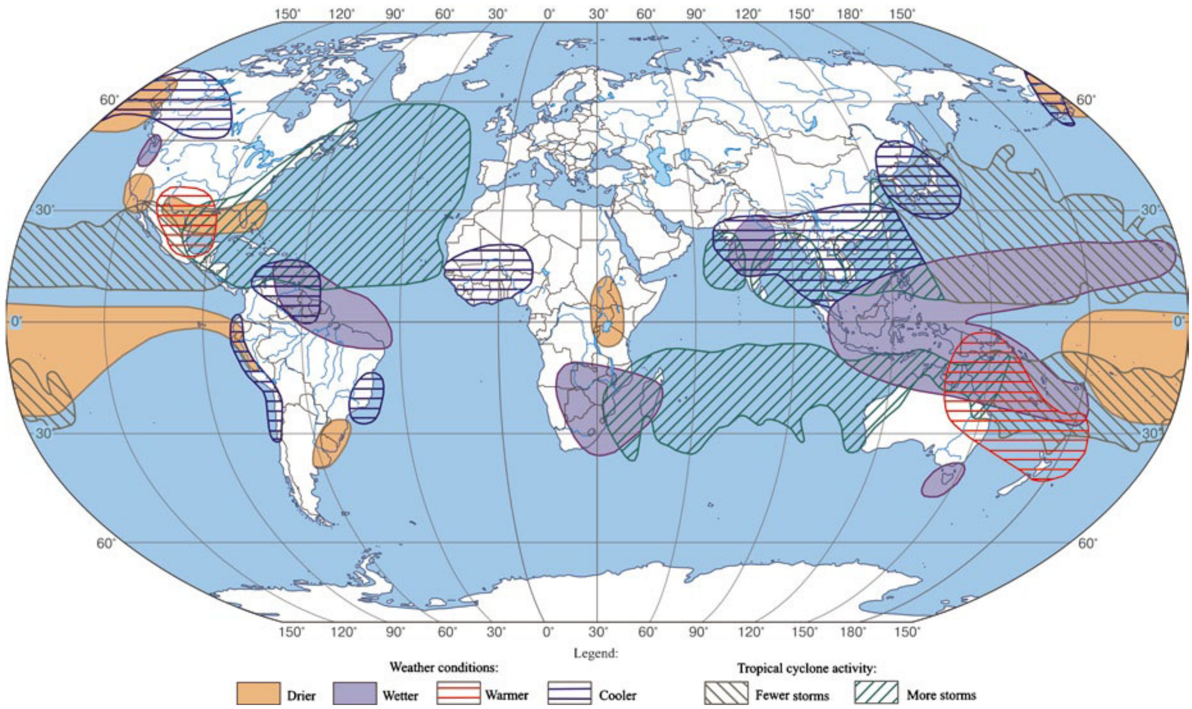

Fig. 4.5 Anomalies during La Niña (World map of natural hazards 2009. Reproduced with permission of Munich Re-Geospatial Solutions)

The effects on *water transport* are distinctive. Mass fish mortality and decomposition of dead fish result in the absorption of dissolved oxygen and production of hydrogen sulphide by sulphate-reducing bacteria. The hydrogen sulphide concentration can be so high that the hulls of passing ships change colour and become black where they come into contact with the water. Due to this effect, El Niño is also called '*colourer*' (Veil 1977).

The influence on *livestock farming* is evident through the augmentation of rainfall on the Peru coast. The rainfalls contribute to the abundance of forage for livestock along the commonly droughty coastal zone, which brings prosperity to the local farmers (Allaby 1996).

One can say that El Niño also affects the *mineral resource industry*. The year-to-year increase in guano on the western coast of South America reaches 200,000 ton (Ecological sketches on nature and humans 1988). Owing to the high content of phosphates, guano is valued highly as a high-quality fertilizer, and production of guano makes a considerable contribution to the Peruvian economy. The mass mortality of anchovies

Photo 4.11 These photos (4.11, 4.12, & 4.13) demonstrate the importance of El Nino for many natural processes. The first photo shows the state of vegetation before the arrival of El Nino, in autumn 1987 (Photo credit: F.M. Jaksic)

Photo 4.12 This photo shows the same site during El Nino, it was taken in spring 1988 (Photo credit: F.M. Jaksic)

Photo 4.13 This photo shows the same site after El Nino, it was taken in autumn 1988. All the photos were taken in Lagunillas, south of Coquimbo, in northern Chile (Photo credit: F.M. Jaksic)

causes the wholesale deaths of birds, especially those that produce guano. Their populations may decrease in El Niño years from 30 to 16 million.

The effects of El Niño on human activities are illustrated by Photos 4.11–4.13.

4.4 Icebergs

An *iceberg* is a floating or aground large block of glacier ice. The extent of icebergs on the Earth is illustrated in Fig. 4.6. In the *northern hemisphere*, their major source is the Greenland glaciers: they are responsible for 90% of the icebergs in this hemisphere, and their annual volume reaches 240 million cubic metres of ice a year (Dynamics of snow and ice masses 1985). The average *lifetime* of Arctic icebergs is 4 years (Monin and Krasitsky 1985).

In the *southern hemisphere*, icebergs originate on the ice shelf of Antarctica. The greatest numbers are produced by the Ross Ice Shelf and the Filchner Ice Shelf (Encyclopaedia ocean-atmosphere 1983). The volume of annually formed ice in the Antarctic icebergs exceeds one billion cubic metres per year (Neshyba 1991). The average *lifetime* of Antarctic icebergs is 13 years (Astapenko 1986).

The *velocity of iceberg travel* can be high. For example, it reaches 4 km/day in the Weddell Sea (Kotlyakov 1994). Icebergs move mainly due to ocean *currents*, while the role of *wind* in iceberg motion is insignificant. On average, the volume of an iceberg that falls below the waterline is 0.83 of the total volume for shelf icebergs and 0.88 for the remainder of icebergs (Dynamics of snow and ice masses 1985). As they drift, icebergs often touch the sea bottom, leaving *furrows*. The *largest furrows* have been recorded in the Weddell Sea (Antarctica). Their maximum *width* is 250 m, while the maximum *depth* is 25 m (Astafyev et al. 1997).

Icebergs influence the following objects and *kinds of human activity*: (1) water transport; (2) pipeline transport; (3) oil and gas extraction from the sea bottom; (4) submarine communication lines; (5) water supplies; and (6) power engineering.

The effects of icebergs on *water transport* may be either negative or positive. The greatest danger is represented by icebergs carried to *shipping lanes*. They create the maximum threat to navigation in the North Atlantic, where the busy shipping routes connecting Europe with North America pass. In this area, 650 km to the south of Cape Race, Newfoundland, the ocean liner *Titanic* collided with an iceberg on the night of 14 April 1912.

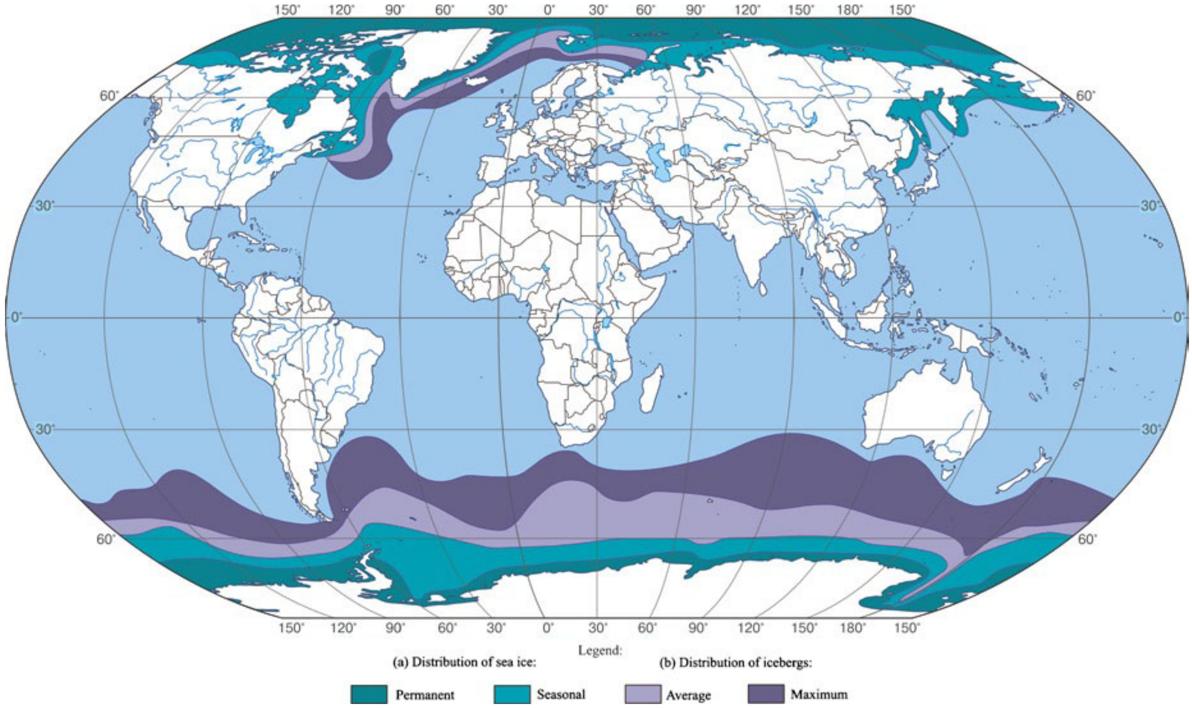

Fig. 4.6 Distribution of sea ice and icebergs (Resources and environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of the Sciences)

Photo 4.14 Icebergs vary greatly in size. This photo shows the B-15 iceberg, which is one of the largest known. It came off the Ross Ice Shelf, Antarctica, on 17 March 2000. It had dimensions of 300 by 40 km (Photo credit: U.S. National Aeronautics and Space Administration)

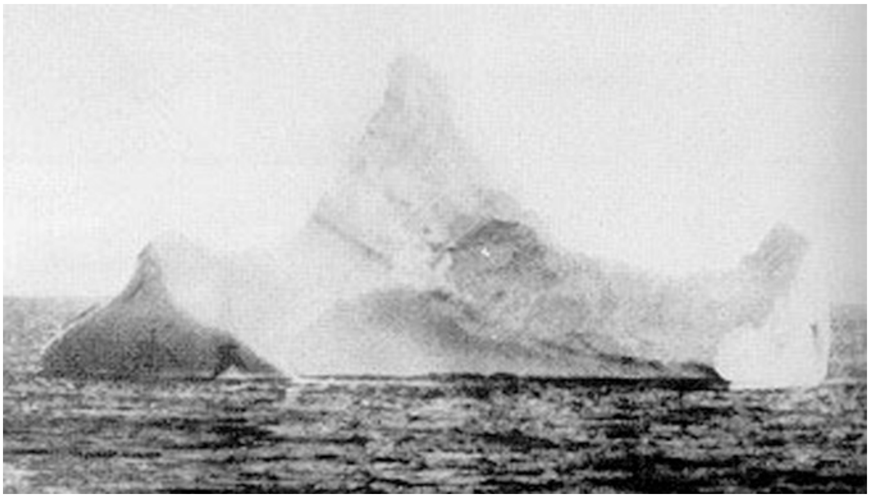

Photo 4.15 The well-known catastrophe of the *Titanic* was caused by a collision with an iceberg on 14 April 1912. This photo of the fatal iceberg was taken by the chief steward of the liner *Prinz Adelbert* who stated the berg had red anti-fouling paint of the kind found on the hull from below *Titanic*'s waterline. The iceberg was reportedly 60–120 m long and 15–30 m high (Photo credit: http://en.wikipedia.org/wiki/RMS_Titanic,15 April 1912)

The establishment of the special *International Ice Patrol* has significantly reduced the danger of collisions with icebergs. If, early in the twentieth century, six ships were lost every year for this reason (Myagkov 1995), then, after 1914, such events became relatively rare. For example, on 30 January 1959, the Danish cargo and passenger vessel *Hans Hedtoft* collided with an iceberg about 56 km south of Cape Farewell and quickly sank, killing 95 people (Kotlyakov 1994).

The danger of icebergs to vessels is aggravated by the fact that they often have, in their underwater portions, protuberances – *rams* – extending hundreds of metres beyond them. When a ship moves close to an iceberg, there is the risk of colliding with such a ram (Kotlyakov 1994).

Although they constitute a threat to navigation, icebergs sometimes provide *benefits* to seafarers. For example, whalers in Baffin Bay often ride out behind an iceberg, using it as a massive floating breakwater (Dynamics of snow and ice masses 1985).

If the influence of icebergs on water transport is gradually becoming less, then their effects on *pipeline transport* (as well as on marine oil and gas extraction and underwater communication lines) is increasing, related to the intensification of economic activity where they are present, especially in the Arctic.

A danger of icebergs for *marine oil* and *gas extraction* lies in the possibility of dynamic impact. Because of the increasing rates of prospecting and development of offshore deposits, the probability that icebergs may enter areas of drilling and field operations is quite high. At present, such a threat is credible, for example, in the Labrador Sea. There, several tow boats are permanently on duty, with the goal of deflecting iceberg drift trajectories from the eastern coast of Canada and western coast of Greenland in order to prevent their collision with offshore drilling units or drilling rigs (Dynamics of snow and ice masses 1985).

The effect on *underwater communication lines*, as in the case of pipelines, is exerted when they plough bottom sediments. For example, 25 breakdowns of communication cables caused by icebergs were recorded in the Labrador Sea during the period 1960–1970 (Astafyev et al. 1997).

A role of icebergs in the *water supply* is, for the present, only hypothetical. There are elaborate engineering designs for delivering icebergs to the coasts of Saudi Arabia, Portugal, and other countries. According to the estimates, five to six tugboats of 15,000 horsepower each would be needed to tow an iceberg 1 km long, 600 m wide, and 300 m high (Zalogin and Kuzminskaya 2001). In addition, due to the large draught of icebergs, reaching 150–200 m, it would be impossible to bring them closer to a shore than 20–40 km; it would be necessary to construct pipelines or to arrange shuttles of tankers to deliver the water to shore (Kotlyakov 1997).

The *value* of icebergs in supplying *energy* lies in the possibility of using the difference between the temperatures of ocean water and the temperatures of icebergs for energy generation. For the time being, this possibility has been studied purely in theory.

The effects of icebergs on human activities are illustrated by Photos 4.14 and 4.15.

4.5 Sea and Lake Ice

Sea ice occupies on Earth, on average, 26.3 million square kilometres (Fig. 4.6) at an *average cover thickness* of 1.5 m (Voitkovsky 1999). The *volume* of annually formed sea ice is 33,000 km³, including 13,000 km³ in the northern hemisphere and 20,000 km³ in the southern hemisphere (Kotlyakov 1994).

Lake ice occurs strictly in the northern hemisphere. For the Earth as a whole, the ices on lakes and storage reservoirs occupy 1.17 million square kilometres, while their volume is 895 km³ (Atlas of snow and ice resources of the world 1997, vol II, Book 2). Lake ice is not permanent; it is purely a seasonal formation.

The average *lifetime* of sea ice is 1.05 years – 1.3 years in the northern hemisphere and 0.8 year in the southern hemisphere (Glaciological encyclopaedia 1984).

The sea ice cover consists of *drift* ice and *shore* ice. The *average velocity* of the Arctic ice drift is 0.25 km/h (6 km/day). The *record velocities* (13–15 km/h) were recorded in July 1967, in the northern Gulf of Ob (Benzeman 2004). On *lakes* and *storage reservoirs*, the maximum *drift velocity* is 2–3 km/h (Glaciological encyclopaedia 1984).

When ice floes come into contact during drift, the compressive and tangential forces break up the ice and form raised mounds called *hummocks*. In areas of strong ice hummocking, as, for example, in the coastal zone of the Canadian Arctic Islands, they can reach 50% of the whole of an ice mass (Walker 1992).

From the viewpoint of effects on human activities, of chief interest are *grounded hummocks* (large hummocky formations that touch the seabed). Their dimensions can be quite large. For example, in April 1986, a grounded hummock up to 18 m high (at a sea depth of 20 m), with dimensions of 300 × 100 m and mass of about one million tons was observed in Chayvo Bay (north-eastern Sakhalin) (Astafyev et al. 1997). The maximum *depth* of the bottom furrows caused by grounded hummocks reaches 6 m (Surkov 1995). They have been found in the Beaufort Sea, Baffin Bay, Labrador Sea, North Sea, Barents Sea, Laptev Sea, East Siberian Sea, Sea of Okhotsk, and other locations.

Furrows made by grounded hummocks also occur at the bottoms of *lakes*. For example, their dimensions in Lake Erie and Great Slave Lake reach 4.5–6 km long, 60–100 m wide, and 2 m deep (Astafyev et al. 1997).

The *effects* of sea and lake ice on human activities are mainly caused by *three factors* (Voitkovsky 1999): (1) dynamic pressure (at the expense of motion energy of ice masses); (2) abrasive action of ice (when it moves relative to structures); and (3) static pressure (as a result of thermal ice expansion).

Sea and lake ice influence the following objects and *kinds of human activity* (Govorushko 2007b): (1) water

Photo 4.16 When ice floes drift, they often collide and thus form hummocks and create new ice relief forms. The photo shows hummocky ice in the Bering Sea (Photo credit: Yu.D. Bychenkov, Arctic and Antarctic Research Institute, Russia)

Photo 4.17 The major structures of ice hummocks are the sail, which is the part above the waterline, and the keel, which is the lower part. The underwater part of long-lived hummocky ice is usually 3.2 times bigger than the part above the water. As for annual hummocky ice, this ratio is 4.5. The photo shows the process of measuring sea ice hummock height (Photo credit: Arctic and Antarctic Research Institute, Russia)

transport; (2) motor transport; (3) air transport; (4) pipeline transport; (5) underwater communication lines; (6) marine oil and gas extraction; (7) bridges; and (8) water supplies.

As for *water transport*, the effects are exerted directly on ships and the accompanying infrastructure (e.g. lighthouses, berths, piers, offshore breakwaters). The effects on ships are as *follows*: (1) compression of hulls; (2) blockage of motion; (3) creation of difficulties with radio location; (4) effect of bottom ice on anchors; and (5) skiving action on wooden hulls.

Vessels that are in the *compression* zone are subjected to the strongest pressures on the hulls and lose their manoeuvring ability. Ice crushed the vessels *Karluk* in 1913, *Chukotka* in 1931, *Chelyuskin* in 1934, and *Rabochy* in 1938 (Korzhavin 1962). Early in September 1983, the dry cargo ship *Nina Sagaidak* was wrecked as a result of compression in the Long Strait connecting the East Siberian and Chukchi Seas (Benzeman 2004).

Sea and lake ice also affects navigation *in the absence of pressure*. Open pack ice (40–60%) reduces the velocity of vessels by 20–30%. Close pack ice (70–80%) is an insurmountable obstacle for conventional ships, while ice ships lose 20–30% of their speed. At times, close pack ice proves to be impassable even for icebreakers (Kotlyakov 1994).

Under conditions of ice navigation, difficulties often emerge in separating a ship's radar echo signal from coastal objects against the background of *echo signals from ice floes and hummocks* (Reference book of the master mariner 1988). *Bottom ice* accretion on ship anchors sometimes causes them to float up from the seabed. There is also a cutting action of ice. The *sea ice crust* (young ice with thicknesses up to 10 cm) easily cuts the wooden hulls of ships and boats (Kotlyakov 1994).

Sea and lake ice sometimes *damages lighthouses* built near the shore edge. The causes of this are both ice loads and its abrasive action. For example, sea ice destroyed a lighthouse in the Gulf of Bothnia (Baltic

Photo 4.18 Sea ice severely complicates navigation. Open pack ice (40–60%) reduces the velocity of vessels by 20–30%. Close pack ice (70–80%) is an insurmountable obstacle for conventional ships, while ice ships lose 20–30% of their speed. At times, close pack ice proves to be impassable even for icebreakers. The photo shows a ship squeezed by ice in the Beaufort Sea near the northern Alaskan coast (Photo credit: U.S. National Oceanic and Atmospheric Administration)

Sea) late in April 1969 (Bergdal 1972). After 4 years of operation, three lighthouses on Lake St. Francis, Canada, were damaged (inclined or shifted) (Danis 1972).

The impact of sea ice results in destruction of structures such as *piers, breakwaters,* and *embankments.* For example, several small berths were completely demolished in 1972 near Cape Schmidt in the Chukchi Sea (Ogorodov 2003).

The influence of sea and lake ice on *motor*, *rail,* and *air transport* is positive. The ice is widely used for construction of *landing strips* and for *motor transportation*. During World War II, the 'Lifeline Route' built on the ice of Lake Ladoga played a vital part in the Leningrad defence. During the siege of Leningrad, more than 400,000 ton of cargo and 500,000 people were transported (Atlas of snow and ice resources of the world 1997, vol II, Book 2). At the same time, the ice railway passage constructed in the Dvina Gulf (White Sea) was of great importance for unloading Allied convoys in Arkhangelsk (Dynamics and interaction of the atmosphere and hydrosphere 2004).

The effect on *pipeline transport* is related to the plucking by grounded hummocks of bottom sediments. For example, a gas pipeline laid on the bed of Lake Erie in 1965 had numerous ruptures within a zone of intense effect of hummocks on the bed during the period 1967–1971 (Grass 1984). A pipeline constructed on the Great Slave Lake to supply potable water to coastal towns was destroyed by drift hummocks in numerous places within a section 250 m long (Noble and Comfort 1982).

Sea and lake ice is also dangerous to *underwater communication lines*. For example, the laying of a high-voltage cable system was planned in the eastern part of Lake Erie in 1980. During the geophysical survey, furrows 4.5–6 km long, 60–100 m wide, and up to 2 m deep were found in the lake bed (Astafyev et al. 1997).

Sea ice creates considerable difficulty for *oil* and *gas extraction* from the ocean bottom. These difficulties include things such as direct impacts of ice floes, their dumping onto structures, and abrasion of structures under the action of ice. The values of ice loads on floating production facilities reach, according to different data, 3,000 to 20,000–30,000 ton on each facility (Potapov 1994).

The mechanism of the effect of ice on *bridge pillars* is similar to that on the supports of floating production facilities. In one incident, ice created problems for a bridge across the Bay of Quinte (Lake Ontario) in Belleville (Canada). Under the pressure of the ice cover, the stone bridge footings deviated from the vertical by 5–30 cm and were restored to the vertical position only after the ice was removed (Korzhavin 1962).

The use of sea ice for *water supplies* is possible, as the multi-year sea ice is essentially free of salt. Sea ice is also used for the arrangement and functioning of *floating scientific stations* used for studying the ocean near the North Pole.

The influence of sea and lake ice on human activities is illustrated by Photos 4.16–4.18.

4.6 River Ice

The *distribution* of river ice is similar to that of lake ice. This ice forms in rivers located to the north of 35°N, except for regions that are under the influence of the warm Gulf Stream. River ice is practically absent in the southern hemisphere. During a period of its maximum development, ice occupies an *area* of more than 500,000 km^2, and its *thickness* is, on average, 73 cm.

The *freeze-up duration* is from 3 to 8 months in Russia, Canada, and Scandinavia, while it is 6–8 months in Alaska. In regions with unstable winter conditions (south Kazakhstan, central Asia, the Caucasus, central and south-eastern Europe, the northern states of the United States), the refreezing and opening of rivers are possible during winter (Glaciological encyclopaedia 1984). An increase in ice *thickness* occurs both from below (due to water crystallization and ice brash straight freezing) and from above (as a result of freezing of water-soaked snow). The *maximum thickness* of river ice cover is 200 cm (Atlas of snow and ice resources of the world 1997, vol II, Book 2).

The effects of river ice on human activities are due to the following *factors*: (1) dynamic pressure (occurs mainly in spring at the expense of the motional energy of ice masses; can reach 1,000–1,500 ton/m^2); (2) static pressure (caused by thermal ice expansion and develops predominately in winter; can be 200–300 ton/m^2); (3) gravity force (load caused by ice crust freezing to structures when the water level changes); (4) abrasive action (resulting from the friction forces between moving ice floes and structures); and (5) lifting force (related to the ice buoyancy).

River ice influences the following objects and *kinds of human activity* (Govorushko 2007c): (1) water transport; (2) water power engineering; (3) water supply systems; (4) bridges; (5) motor transport; (6) rail transport; and (7) air transport.

The effects on *water transport* are expressed in problems with navigation, difficulties in operation of shipping locks, damage to river transport infrastructure, and other problems. In the majority of cases, river ice is an *obstacle* for navigation; therefore, dates that rivers are navigable are determined by the freeze-up and ice movement.

Problems related to plugging of a ship's pumping unit with *sludge ice* often occur (Atlas of snow and ice resources of the world 1997, vol II, Book 2). Other difficulties are related to *bottom ice*, which accumulates on anchors and causes them to float up to the surface (Glaciological encyclopaedia 1984).

River ice does not infrequently damage or destroy *river transport infrastructure* (e.g. berths, piers, lighthouses). Static pressure and gravity act on moorage walls and piers, and dynamic pressure and abrasive action affect them when the ice is moving. Effects on lighthouses are mainly observed during ice movement. In one incident, a lighthouse on the St. Lawrence River was overturned by ice (Danis 1972).

The effects of river ice on *water power engineering* are mainly related to hydroelectric dams. The factors of influence are static impact of ice and its gravity force when the ice freezes to a dam and remains suspended when the water level drops. Numerous examples of the destruction of dams in Ohio, Mississippi, and West Virginia (United States) are presented in a monograph by K.N. Korzhavin (1962). For example, in February 1899, 52 m of a dam in Minneapolis (Minnesota, United States) were destroyed by ice with a thickness of 1.2 m when the temperature changed from −22°C to −8°C. The static pressure in this case reached 16.7 ton/m^2.

The effect of river ice on *water supplies* is typical. Due to the high ability of *sludge ice* to stick to anything with which it is in contact (Beltaos 1996), interruptions in water delivery occur when pipes become plugged (Atlas of snow and ice resources of the world 1997, vol II, Book 2).

The influence of river ice on *bridges* occurs with participation of practically all factors, but the major factor is the *dynamic pressure* on bridge pillars that develops during the spring ice drifting. For example,

Photo 4.19 The influences of river ice on transport also can be positive. As to strength, river ice is significantly superior to sea ice. River ice is widely used to lay ice roads, ice passages, and aircraft take-off runways. This hunter is conveying equipment by snowmobile on the frozen Bikin River (Primorsky Krai) (Photo credit: A.M. Panichev, Pacific Geographical Institute, Vladivostok, Russia, February 2005)

a bridge across the Connecticut River near Brattleboro (Vermont, United States) was carried away eight times during a period of 120 years. Examples of damage to bridges owing to *static pressure* are also known. For example, a pier of a bridge in Canada, weighing as much as 1,000 ton, deviated from the vertical by 5 cm. The ice pressure force reached 71.3 ton/m² (Korzhavin 1962).

The influence of river ice on *motor*, *rail,* and *air transport* is positive. River ice is far stronger than sea ice. The laying of *winter roads* on river ice is widely used. Where there are no permanent bridges, *ice passages* are used. For example, near Yakutsk (Russia), a passage across the Lena River is built every winter. River ice cover is widely used as *landing strips* for airplanes and helicopters. *Loggers* stockpile wood on ice that will drift, while *oil workers* use it to transport heavy loads and for installation of equipment (Atlas of snow and ice resources of the world 1997, vol II, Book 2).

The effects of river ice on human activities are illustrated by Photo 4.19.

4.7 Ice Jams

4.7.1 Spring Ice Jams

A *spring ice jam* is a pile-up of ice floes during ice drift in river narrows and scrolls.

Spring ice jams are *most characteristic* of rivers that are breaking up downstream, which is inherent in the *following*: (1) rivers running from south to north; (2) rivers with mountain and foothill upper reaches and lower reaches in the plains; and (3) rivers having sections with large differences in the break-up dates.

Rivers in the *first category* include the Pechora, Lena, Yenisei, Yana, Indigirka, Kolyma, Mackenzie, and rivers flowing into James Bay (Canada) (Harricana and others).

In the *second category*, one can include the Amur River and its tributaries (Zeya, Bureya, Sungari, Ussuri); upper reaches of the Irtysh, Ob, and Yenisei; as well as the Tom, Yukon, Danube, Dniester, Rhine, and the Liard (Canada).

Examples of rivers belonging to *the third category* include the northern Dvina River near Arkhangelsk where the river meets the White Sea; the Hay River where it meets the Great Slave Lake; the Moira River near Belleville, where the river meets Lake Ontario; and the Thames and Sydenham Rivers where they meet Lake St. Clair in Canada (Myagkov 1995; River ice jams 1995; Samoylov et al. 1995).

The *ice jamming mechanism* is as follows. In spring, water flow increases as the snow melts, and the ice cover bulges in the middle, forming a bump. Along the shores, cavities appear, breaking ice from the shore that floats up. The ice cover is then crushed into separate ice floes due to currents. The drifting ice causes the formation of ice jams in locations where opening of the river is delayed because of greater thickness and strength of the ice cover.

The *lifetime* of ice jams reaches 12–15 days. The water level of a river can rise to 10 m and more above the peak flood level. The maximum height of rise over the low stage is characteristic of the narrowing of the Lower Tunguska River valley (Russia), where it is 35–40 m. The *lengths* of ice jams can reach 50–100 km (Myagkov 1995). The *volume* of ice within clogged sections of large rivers can reach 50–200 million cubic metres (Kotlyakov 1994). The destruction (breach) of an ice jam most often is caused by the joint action of increases in water flow, solar radiation, and warm air.

The *danger of ice jams* is mainly related to *two factors*: (1) considerable water level rise and (2) dynamic ice pressure. They influence economic entities and human activities such as the *following*: (1) residential construction; (2) river transport; (3) bridges; (4) motor roads and railroads; (5) crop production; (6) water power engineering; (7) water supplies; (8) pipelines; and (9) transmission lines.

Both factors take part in the effects on *settlements*. Numerous examples of flooding of settlements in Canada are given in the monograph *River Ice Jams* (1995). For example, in May 1989, 1,800 people needed to be evacuated from *Fort Albany* in northern Ontario (Canada). In 1979, more than 600 residents of the city of Dawson on the Yukon River were left without a roof over their head; and in 1982, the city of Aklavik on the Mackenzie River was flooded. In 1985, the city of Chatham on the Thames River was flooded as well. Many other examples of such flooding could be given.

As a rule, both flooding and ice pressure affect buildings. Nonetheless, in some cases, just *dynamic action of ice* is a determining factor. For example, an ice flow up to 2 m in height formed as a result of a breach of an ice jam on the Winisk River in May 1986; the ice caused damage and deaths in the settlement of the same name near Toronto (Canada). During 15 min, 53 of 60 existing buildings were destroyed and 2 persons of 125 residents were killed (River ice jams 1995).

The effects on *river transport* include the *following*: (1) loss and damage of ships; (2) stoppage of navigation; and (3) damage to objects of the transportation infrastructure. Ships are lost or damaged at the stage of the jam breach. For example, an ice jam on the Yenisei River (near the village of Melnichny, 60 km upstream of Turukhansk) in 1943 resulted in the loss of one-third of the Yenisei fleet: the ships passing the winter in the Dry Tunguska River mouth were, within 20–30 min, cast ashore, overturned, or shoved into each other (Nezhikhovsky 1988).

Ice jams blocking waterways are often *obstacles for navigation*. For example, a jam late in April 1984, in the narrow 64-km (40-mile) passage that connects Lake St. Clair with Lakes Huron, Superior, and Michigan, stopped navigation along the whole system of the Great Lakes, delaying 87 cargo ships. The daily losses owing to downtime reached US$1.5 million (River ice jams 1995).

The effects on *river transport infrastructure* are typical. For example, an ice jam in the spring of 1929 demolished a pier on the Yenisei River (Korzhavin 1962). Berths and piers were damaged repeatedly on the St. Lawrence River until adequate preventive measures were taken. Especially significant damage was caused on 9 May 1874 (US$1 million at the currency values of those times). Extensive similar damage also has been recorded on the Missouri River in the United States, the Nicola River in British Columbia (Canada), and others (River ice jams 1995).

Damage to *bridges* is also widespread. It is caused by two *factors*: (1) ice consolidation in the bridge spans, which makes it necessary to take into account the maximum heights of ice jams in their design, and (2) ice pressure on bridge footings. Bridges have been damaged or destroyed by ice jams quite frequently. Examples include the destruction or damage of the railway bridges on the Miramichi River near Boiestown and a 290-m bridge near Perth-Andover (both in New

Photo 4.20 Spring ice jams habitually impact bridges. The photo shows a bridge across the St. John River near Dickey, Maine (United States) that is threatened with destruction (Photo credit: Spyros Beltaos, National Water Research Institute, Environment Canada, February 1981)

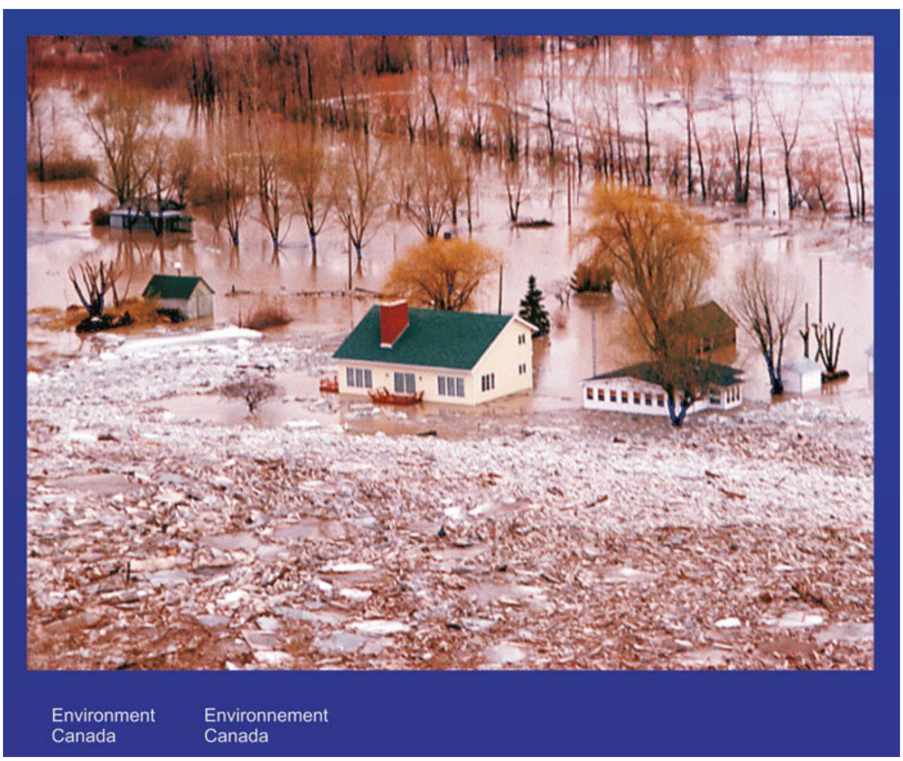

Photo 4.21 The impacts of spring ice jams on dwellings lie in the considerable water rise and dynamic force of the ice. The photo shows flooding caused by an ice jam near the mouth of the Thames River, Ontario, Canada (Photo credit: Spyros Beltaos, National Water Research Institute, Environment Canada, February 1981)

Photo 4.22 May 1998 brought several heavy ice jams that caused inundations in the middle of the Lena River and in a couple of inflows in the river basin. Flooding affected 135 localities, and 14 people and 2,728 cattle died. One can see the roofs of floating houses (Photo credit: I.S. Seleznev)

Photo 4.23 The impacts of ice jams on motor transportation are not widespread. Most often, they lie in the flooding of roads. Still, ice jams sometimes generate ice blocks that block roadbeds. This photo illustrates exactly this case (Photo credit: National Weather Service, U.S. National Oceanic and Atmospheric Administration, 2 February 2005)

Brunswick, Canada), and a bridge on the Saint-Jean River in Quebec (Canada) (Myagkov 1995).

Ice jams result in flooding of *motor roads* and *railroads*. Sometimes, transport is complicated due to piles of ice floes on roadways. One such event was caused by an ice jam in a motor road near *Fredericton* (New Brunswick, Canada) in 1983 (River ice jams 1995). The effects of ice jams on *crop production* differ little from those of river floods and, therefore, are not discussed here.

The impacts on *water power engineering* are characteristic of low-head power plants and involve the pressure on the dam and clogging of discharge openings, reducing the water head. In addition, when

Photo 4.24 The impact of ice jams on aviation amounts to flooding of runways. The photo shows the airport in Aniak, Alaska (United States), which was inundated due to an ice jam in the Kuskokwim River (Photo credit: National Weather Service, U.S. National Oceanic and Atmospheric Administration)

the water level rises, pressure of the ice-clogging mass on the hydropower structures is possible. For example, ice broke through windows into the generator hall of the Ontario hydropower plant on the Canadian shore of the Niagara River as a result of an ice jam on 27 January 1938. The generator was covered with ice up to 5 m thick (Korzhavin 1962).

Ice jams sometimes create difficulties for *water supply systems*, damaging pumping stations located too low or shallowly buried water intakes. The effects on *pipelines* are similar. Where a pipeline crosses a river, it can be damaged by the upper part of the ice jam. In the case of an underwater river crossing, the problem of plucking of bottom sediments by ice floes arises. The impacts on *transmission lines* are related to flooding or, in rare instances, pressure of ice floes when a transmission line is situated near a riverbed.

The *economic significance* of ice jams is great. The financial losses for Canada are estimated at US$60 million a year (River ice jams 1995). According to data of a number of authors (Carlson et al. 1989), losses for the United States are about US$100 million a year. We estimate total *economic losses* on a global scale at US$500–600 million, and a yearly *mortality* related to them at ten people (Govorushko 2007a).

The effects of spring ice jams on human activities are illustrated by Photos 4.20–4.24.

4.7.2 Autumn Ice Jams

An *autumn ice jam* is an accumulation of sludge and brash ice within a riverbed, causing a constraint of the cross section of the river and water level rise. This phenomenon is characteristic of many rivers in Europe, Asia, and North America, north of 35°N. In *Europe*, autumn ice jams are typical of the following rivers: Northern Dvina, Pechora, Onega, Kem, Tuloma, Ponoi, Vistula, Western Dvina, Niemen, Neva, Danube, Dniester, Don, and Southern Bug.

In *Asia*, autumn ice jams are observed in the Yenisei River; Angara River; rivers of Transbaykalia, central Asia, Sakhalin, and Kamchatka; Altai (Biya, Katun, Koksa, Tom, and other rivers); and the Amur basin. In *North America*, autumn ice jams are characteristic of the St. Lawrence, Mackenzie, and Yukon Rivers, and the upper reaches of the Columbia and Fraser Rivers. Autumn ice jams also appear on the Bou, Red Deer, Israel, and White Rivers. (Atlas of snow and ice resources of the world 1997, vol II, Book 2).

The autumn ice jam is a phenomenon analogous to the spring ice jam. It is also an accumulation of icy material within a riverbed, resulting in increases in water levels at sites of accumulation and upstream. One can identify *two major differences* between the two (Nezhikhovsky 1988): (1) an autumn ice jam consists of an accumulation of loose icy material (lumps, sludge ice, particles of bottom ice, fragments of shore ice, relatively small ice floes), while a spring ice jam is an accumulation of small floes and brash ice; and (2) autumn ice jams are observed in the early winter and within those river sections where ice formation occurs from the lower parts of the river to the upper parts, whereas spring ice jams form late in winter when ice breaks up on the river and its edge moves downstream.

The *necessary condition* of the autumn ice jam is an appearance of cream ice within the riverbed and its involvement under the ice cover edge in river sections with flow velocities of more than 0.4 m/s. Different obstacles in a riverbed – islands, shallows, boulders, narrowing, sharp bends, and so on – contribute to the formation of autumn ice jams (Accidents and catastrophes 1995).

The *lifetime* of an autumn ice jam can be several days to the whole winter. The *height* of the water level rise depends, first of all, on the length of a section with steep inclination. On average, the rises related to autumn ice jams reach 2–3 m. However, they are much more on the great slush ice run rivers, and they reach 5–6 m for the Northern Dvina, Western Dvina, and rivers of Altai; 6–7 m for the Yenisei and Angara Rivers; and 12 m for the Naryn River (Myagkov 1995). The *thickness* of an autumn ice jam accumulation can exceed 10 m, the *length* can reach 10–20 km, while the *volume* of sludge ice in an autumn ice jam can reach 100 million cubic metres (Kotlyakov 1994).

The *impacts* of autumn ice jams on *human activities* can be subdivided into the effects of *floods caused by autumn ice jams* and the effects of ice accumulations (i.e. *autumn ice jams proper*). The effects of floods caused by autumn ice jams are, in many respects, similar to those of run-off floods on the whole and to those of floods due to ice clogging in particular. However, there are also some differences, which are mainly related to the season when they occur. As for effects on *crop production*, losses from autumn ice jam floods are lower because the harvest already has been taken in.

The situation is similar for *livestock farming*, as, by the early winter, livestock is absent on pastures, fodder crops have been harvested, and fodders have been procured.

At the same time, the effects on *civil* and *industrial engineering* are sometimes more serious. Because floods related to autumn ice jams occur early in winter, the flowing water is frozen, and the ice needs to be cut away and removed from the premises. By virtue of their long duration, the effects of floods related to autumn ice jams exceed those related to spring ice jam floods.

Autumn ice jams proper *mainly influence* water power engineering, water supply systems, bridges, motor roads and railroads, pipelines, and river transport.

The impacts on *water power engineering* are related to clogging by compact sludge ice of openings in the body of a dam through which water enters the turbine fins. A sharp reduction in head takes place that results in decreases in power generation. More than 30% of annual economic losses related to autumn ice jams in Canada is related to this problem (River ice jams 1995).

The influence on *water supply systems* is identical. It results both from clogging with sludge ice of insufficiently buried water intakes, which causes a reduction in the head, and from pressure on the water intakes by the ice jam mass. Known cases of damage to water intakes have occurred on the Ob, Dnieper, and Western Dvina Rivers (Atlas of snow and ice resources of the world 1997, vol II, Book 2).

The effects on *bridges* are caused by the pile of the masses of autumn ice jams on the footings and by their flooding when water levels rise. The situation is similar with *pipelines* and *river transport*. As an example, one can present events when autumn ice jams have damaged berths on the Neva, Katun, Amu Darya, Amur, and other rivers (Atlas of the world snow-ice resources 1997, vol II, Book 2).

On the whole, the influence of autumn ice jams on *motor roads and railroads* is also similar to that of spring ice jams., There is one difference, however: due to autumn ice jams, seasonal river ice crusts are formed in many regions of Siberia and mountain areas of central Asia that create difficulties for road traffic (Myagkov 1995).

4.8 Waterfalls

A *waterfall* is a fall of water in a river from a terrace crossing the riverbed. Waterfalls occur on all continents except Antarctica. Among the countries with the *highest concentrations* of waterfalls are the small highland Kingdom of Lesotho in southern Africa (sometimes called the country of 3,000 waterfalls) and Norway, which is called the waterfall country.

Sometimes, waterfalls are situated in rows along *particular lines*. Generally, these are terraces formed

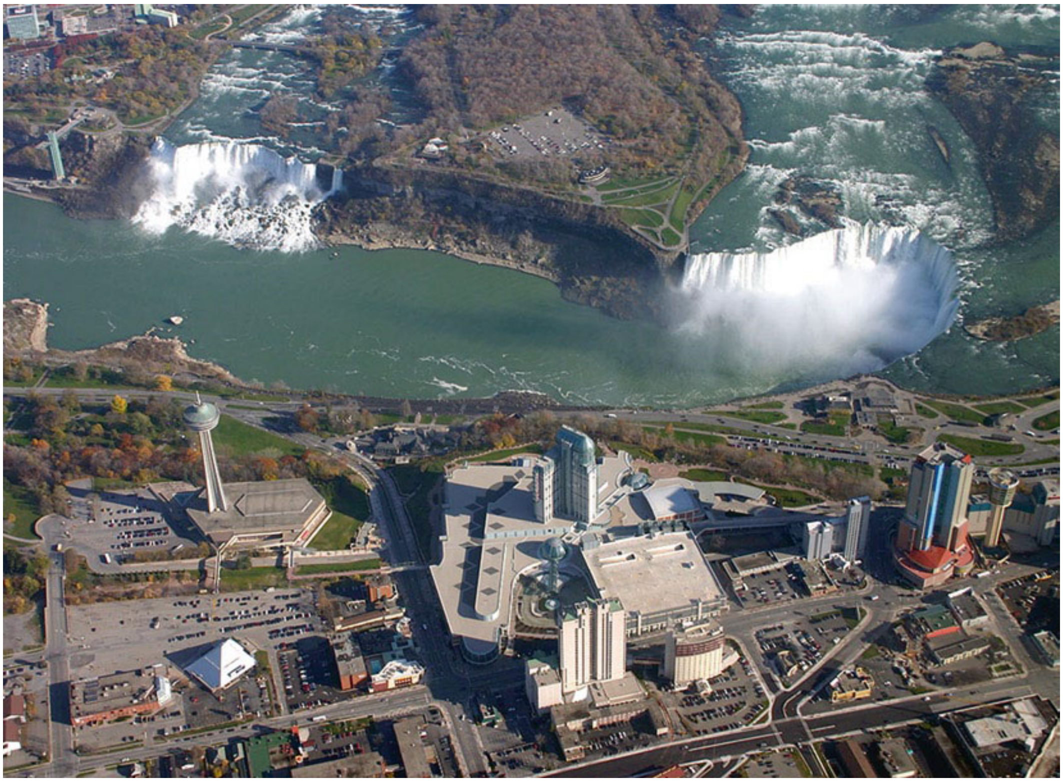

Photo 4.25 In some areas of the world, waterfalls are prominent tourist attractions. Niagara Falls, at the border of the United States and Canada, embodies this idea. The falls are surrounded by hotels and motels, view towers, and the tramway. This aerial view of Niagara Falls was taken from 3,500 ft in November 2005 (Photo credit: http://en.wikipedia.org/wiki/Waterfall)

by the edges of horizontal beds of hard rocks. For example, a waterfall line is formed within the strip stretched along the Atlantic coast of the United States, between the crystalline foot of the Appalachian Mountains and the east coastal plain. All rivers flowing from the Guiana upland side toward the Amazonian lowland also form waterfalls (Yakushko 1986).

According to the ratio of width to height of the fall of water, *two types of waterfalls* have been identified: (1) *Niagara-type* waterfalls (for which the width of the waterfall exceeds the height); and (2) *Yosemite-type* waterfalls (for which the height exceeds the width).

Water falling from a terrace usually begins to rotate near its foot. In this case, water entrains boulders and pebbles and gouges *giant's kettles* deep in the riverbed. The depths of kettles of some waterfalls are commensurable with their heights. For example, the depth of the kettle and the height of Niagara Falls are identical and reach 50 m (Arseev 1987).

Owing to the rotational motion of fragments and the dynamic impact of the water mass, the basic terrace is *undermined* and its upper part proves to be overhanging a cavity. Periodically, the top edge of a terrace comes down (Shchukin 1960). The long-term process of the undermining of the terrace and its periodic failure results in a gradual displacement of the waterfall up the river (so-called retreating or *regressive erosion*).

The *rates of regressive erosion* for different waterfalls and even for different parts of one waterfall differ greatly. For example, the waterfall on the Niagara River on the US side retreats by 4 cm/year, while on the Canadian side, it retreats by more than 1 m a year. It is projected that it will disappear in 25,000–30,000 years, reaching Lake Erie (Chernysh 2000).

Waterfalls affect the following *kinds of human activity*: (1) water power engineering; (2) water transport; (3) forest industry; (4) recreational activities; and (5) medical care.

The influence on *water power engineering* is positive. The energy of falling water is used to rotate turbines, generating electricity. Among the waterfalls on which *hydropower stations* have been erected are Niagara Falls and Grand Falls (on the Missouri River) in the United States; Rhine Falls in Germany; Trollhättan Falls in Sweden; Paulo Afonso Falls on the São Francisco River in Brazil, Tis Abay, or Blue Nile Falls, in Ethiopia; Owen Falls on the White Nile River in Uganda; and Victoria Falls on the Zambezi River. The maximum contribution of waterfalls in power engineering is made by the waterfalls in *Iceland*. There, they provide 20% of the total electric power produced.

The impact of waterfalls on *water transport* is in hindering navigation. The prime means for solving this problem is the construction of bypass canals. For example, Niagara Falls blocked a passage to the Great Lakes for great seagoing ships. This drawback was eliminated by means of bypass canals. In 1959, seagoing ships passed for the first time through the St. Lawrence River to the Great Lakes (Arseev 1987). The mechanism of influence on the *forest industry* is analogous and lies in their creating difficulties for timber rafting.

The effects of waterfalls on *recreational activities* are great. In any region, waterfalls are fashionable haunts. The best-known waterfalls are among the greatest tourist attractions. The most striking example is Niagara Falls. Around it, hotels, motels, watchtowers, and an aerial tram have been constructed. On both shores, galleries have been built where tourists are delivered to the waterfall foot. Niagara Falls is visited by 20 million tourists every year (http://en.wikipedia.org/wiki/Niagara_Falls#Power). Other *great tourist attractions* include Yosemite Falls (California, United States), Tugela Falls in South Africa, Iguazu Falls on the boundary of Brazil and Argentina, and a number of other waterfalls.

One effect of waterfalls in *medical care* is related to the balloelectric effect (hydroaeroionization). The water jets falling from a great height break against the stone bed and, mixing with air particles, acquire an electric charge (either positive or negative) under the action of ultraviolet rays. In addition, the sound of falling water has a sedative effect. The fine mist spray also has a wholesome effect on the central nervous system and cardiovascular system of humans.

The influence of waterfalls on human activities is illustrated by Photo 4.25.

4.9 Tides

The *tides* are periodic variations in ocean levels caused by attractive forces (gravitational fields) of the Sun and the Moon.

Their *origin* is caused by the action of gravity. One celestial body in the Universe excites the tides in another celestial body. The *value of the tide-generating force* of a body is proportional to the body mass and proportional to the cubed distance from it to the other body (in this case, Earth) (Encyclopaedia ocean-atmosphere 1983). The *largest tide-generating force* on Earth is caused by interaction of the Earth and the Moon. The effect of the Sun is 2.17 times less.

The *tidal height* depends on the relative positions of the Moon and the Sun. The highest tides are observed when both heavenly bodies are in line. The lowest tides occur when the Sun and the Moon are crosswise relative to the Earth; that is, when they form a right angle. Tide amplitudes are shown in Fig. 4.7. In a particular geographic region, tidal height *depends on* the configuration of the coastline, bottom relief, and other factors (Monin and Krasitsky 1985).

In *lakes* and *storage reservoirs*, tides are low. For example, they reach only 8 cm in the Caspian Sea and Lake Michigan (Arsenyev and Shelkovnikov 1991). As for small lakes, the tides in them do not exceed fractions of a millimetre (Encyclopaedia ocean-atmosphere 1983). The most significant tides that have been recorded include the following: 19.6 m in the Bay of Fundy (northeastern coast of Canada); 18 m in Argentina; 16.3 m in England; 14.7 m in Granville, France; 14 m in Australia; 13 m in Penzhinskaya Bay, Sea of Okhotsk; 12.4 m in India; 12.4 m in Mexico; and 11 m in Kandalaksha Gulf (White Sea) (Koronovsky and Yasamanov 2003).

The effects of tides on human activities are caused by *two factors*: (1) level fluctuations and (2) tidal currents. The tides affect the following *human activities* to the greatest extent: (1) water transport; (2) military activities; and (3) mining operations on continental shelves.

The tides are of extreme importance for *navigation*. *Tidal currents* create significant difficulties for navigation in many seas, because their directions and speeds vary continuously. In order to take them into account in navigation, information on the elements of tidal currents is placed in special atlases and tables, sailing

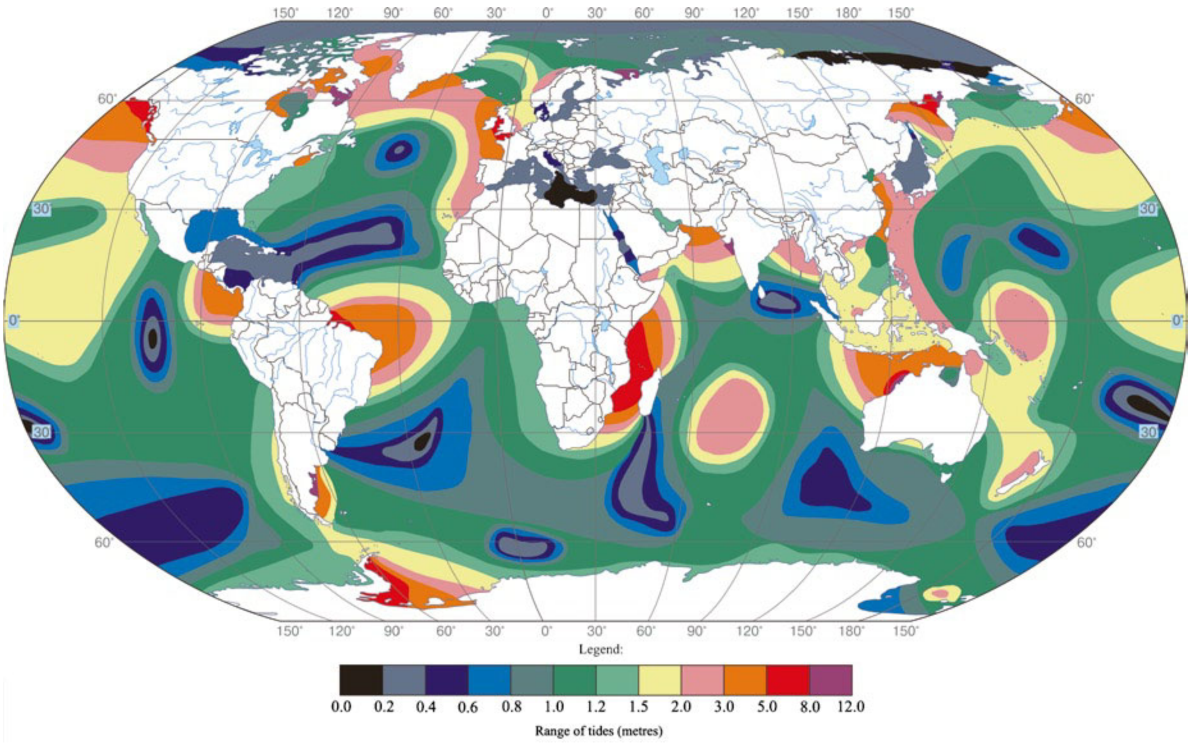

Fig. 4.7 Global tidal range (http://www.meted.ucar.edu/oceans/tides_intro/print.htm. Reproduced with permission of Dr. J. Chittleborough, National Tidal Centre, Australia)

directions, hydro-meteorological surveys, and charts. This information allows navigators to determine their direction and speed at any point at a given instant (Reference book of the master mariner 1988).

Water *level oscillations* are also of great importance. In navigating in coastal areas and, especially, in calling at ports located within bays that go far inland, the danger of grounding increases abruptly. The successful berthing in a port does not always solve this problem. Ships should be safely moored to a pier; otherwise, they may turn over during low tide when the water is not high enough to keep vessels afloat (Jensen 1994).

The major effect of tides on *military activities* is, in many respects, related to navigation. The consideration of tides is of great importance in planning and accomplishing the landing of troops. For example, the tide was very important for the landing of troops when the Second Front was opened in 1944. About 8,000 naval vessels and small craft took part in this operation. The most favourable times for the invasion were on June 5, 6, and 7 (Carter 1977).

These events illustrate a combined effect of tides on military activities. One example of the effect of sea *level fluctuations* is the catastrophe of Julius Caesar's fleet. During an incursion into Britain in 55 BC, the fleet apparently went aground during low tide and was broken by waves (Carter 1977).

The influence of *tidal currents* became fully apparent late in 1942, at the last stage of battles for the important strategic point in the Solomon Islands – Guadalcanal. Here, the stranded Japanese troops received rations and fighting equipment for a long time from torpedo boat destroyers and submarines, which at a certain stage of the tidal current, would throw the rubber containers overboard and leave the hot spot. Later on, the tidal current would deliver these containers to the section of shore occupied by the Japanese troops (Bogdanov 1994).

To some extent, the tides create difficulties for *oil and gas extraction* from the seabed and offshore placer mining.

The effects of tides on human activities are illustrated by Photos 4.26 and 4.27.

Photo 4.26 This photo shows a tidal surge 2 m high in the mouth of the Yangtze River. In springtime, it reaches 3 m. Such surges occur in approximately 60 estuaries all over the world. This phenomenon acquires maximum intensity on the Amazon River. The heights of surges there reach 10 m; the speeds, 7 m/s; and the lengths, 300 km (Photo credit: H. Jesse Walker, 17 October 1989)

Photo 4.27 High and low tides are top priority for water transportation. Fluctuations of water levels substantially complicate navigation in coastal areas by increasing the threat of stranding. The photo shows the ship *Lester Johnes* in the tide zone near the mouth of the Nushagak River (Photo credit: Family of Captain John Ellerbe, U.S. National Oceanic and Atmospheric Administration, 1950)

4.10 Waves

Waves are oscillatory movements of the aquatic environment. Waves are an integral part of any water body.

The following *parameters* are used to describe waves: (1) *trough hollow*, the lowest point of the wave; (2) *crest*, the highest point of the wave; (3) *height*, the vertical distance from a hollow to a crest; (4) *length*, the distance between waves moving one by one; and (5) *period*, the time interval needed for a wave to pass a distance equal to its length. The distance travelled by a wave per unit time is called its *velocity*.

According to the *forces* causing waves, the waves can be divided into forced and free (inertial), progressive and standing. Surface and internal waves are identified according to their arrangement in the water column. Pursuant to causes responsible for waves, they are subdivided into tidal, seismic (tsunami), wind, and baric (seiches). The tides are considered in Sect.4.9, while tsunamis are discussed in Sect. 1.3. Wind, internal, and baric waves are considered below.

4.10.1 Wind-Generated Waves

Wind-generated waves are oscillatory motions of water caused by wind energy when it directly affects the water surface. As there are no absolutely windless places on the Earth, wind-induced waves are, in one way or another, characteristic of any water surface.

The *parameters* of wind-generated waves depend on the following *wave-forming factors* (Khalfin 1990): (1) velocity and direction of the wind and their distributions on the sea surface; (2) duration of the wind action; (3) fetches (distance over which the direction of the air flow moving over the water surface remains invariant); (4) water depth along the fetch and bed slope; and (5) configuration of the coastline.

The *characteristics* of wind-generated waves vary widely. The wave *length* varies from 0.2 to 20 cm for capillary waves (ripples) (Kononkova and Pokazeev 1985) up to 800 m (Zalogin and Kuzminskaya 2001). Their *heights* vary from several millimetres to 37 m (Davidan et al. 1985). The *periods* of wind-generated waves are 0.1 s (Neshyba 1991) to 30 s (Geographical encyclopaedic dictionary 1988). The *velocities* of wave travel vary from 1 to 25–30 m/s (Koronovsky and Yasamanov 2003).

The above figures are the extreme values, which differ strongly from typical values. In the world's oceans, waves with heights of up to 4 m are common, while waves higher than 7.5 m are observed quite rarely (Zalogin and Kuzminskaya 2001). Water areas with maximum recurrence of wind-induced waves greater than 5 m are shown in Fig. 4.8.

The *parameters* of wind-generated waves are closely related to the wind velocity. The average velocity of the highest waves is approximately *80% of the wind velocity*. The average period of waves and their heights increase in proportion to the *first power* of the wind velocity, wave lengths and energy concentrations increase with the *square* of the wind velocity, while energy transport grows in proportion to the *third power* of the wind velocity (Neshyba 1991).

In order to determine the *force of wind-generated waves*, a *nine-mark scale* based on the sea surface appearance is used. So, zero balls corresponds to perfect calm, three balls to initiation of separate feathers at crests, five balls to a periodic blowing by wind of a foam from the feathers, and 8 balls indicates a gale in which the waves are so high that ships in the trough vanish from sight.

The *energy* in wind-generated waves drops quickly with increasing depth. A submarine at a depth of 50 m does not, for the most part, sense heavy seas, whereas storm waves on the surface result in heavy pitching of surface vessels (Neshyba 1991). This is explained by the fact that the sizes of the orbit in which the water particles move decrease *exponentially* with increasing depth. Close to the surface, the diameter of a circular orbit is equal to the wave height. At a depth equal to *one-ninth* of the wave length, it is a half of the height. When the *depth is 50%* of the wave length, the diameter of the circular orbit becomes negligibly small (Harvey 1982). At a depth equal to the *wave length*, it is 535 times less than it is on the surface (Merkulov 1989).

Due to fast fading of water particle movement with depth, wind-generated waves in the open sea can not reach the bottom. However, where the sea depth is half the wavelength, the wave breaking phenomenon arises (Neshyba 1991). Beginning at this depth, there is a *deformation of waves*. At first, the wave length increases and the wave height decreases slightly. Once the waves reach a depth equal to approximately one-sixth of their length on the open sea, the heights of the waves quickly increase.

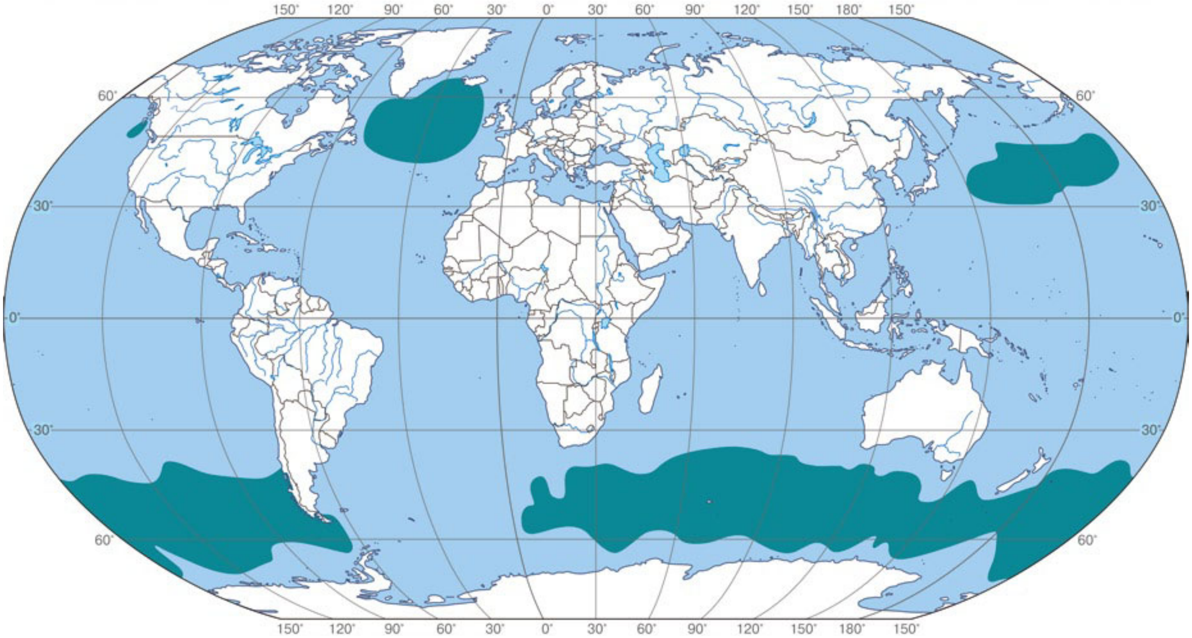

Fig. 4.8 Water areas with maximum recurrence of wind-induced waves greater than 5 m (World map of natural hazards 2006. Reproduced with permission of Munich Re-Geospatial Solutions)

Photo 4.28 Waves pose an ever-present threat for seaside industrial structures and dwellings. Thus, vigorous waves in the state of New Jersey on the Atlantic coast of the United States, posed a threat to innumerable buildings (Photo credit: Peter Shugert, U.S. Army Corps of Engineers, 15 March 1999)

Photo 4.29 Waves have intensive impacts on water transportation. They modify the speed of vessels, especially if their direction is opposite to ship movement. However, waves propagating in the direction ships are headed at times slow them down, too. The photo shows the vessel *Noble Star* in the northern part of the Pacific Ocean (Photo credit: U.S. National Oceanic and Atmospheric Administration, winter 1989)

A sharp increase in the gradient of their slopes with the subsequent turnover of a crest occurs. The sea outfall where there is a deformation of sea waves is called the *surf zone* (Encyclopaedia ocean-atmosphere 1983).

The effects of wind-generated waves are dynamic. They influence the following *kinds of human activity* (Govorushko 2006a): (1) water transport; (2) military activities; (3) oil and gas extraction from the sea bottom; and (4) recreational activities.

Wind-generated waves directly influence both vessels and port infrastructure. The effects on vessels are expressed as changes in the motion of vessels, damage to vessels, and their oscillating motion. To the fullest extent, the *motion of a vessel is decelerated* by waves propagating in the direction opposite to the vessel course; however, the waves going in the same direction as the ship also have a braking effect. At wave heights of more than 4 m, a vessel has to lower its speed or alter its heading (Astapenko 1986).

Wind-generated waves sometimes result in *damage to vessels*. For example, off the eastern coast of Africa, roughly between Durban and Port Elizabeth, so-called 'freak waves' are often found. A considerable ascent of the front slope and heights of up to 15–18 m are characteristic of these waves. During the period 1952–1973, 11 shipwrecks occurred within this area (Davidan et al. 1985).

Typical consequences of wind-generated waves are rolling and pitching *motions* of vessels. They affect the comfort of passengers and crew, and they can result in damage to sensitive cargoes. Effects on *port infrastructure* facilities occur as a result of dynamic pressure of waves and local bed movement within the coastal zone.

The effects on *military activities* involve naval forces, and they are essentially identical to the effects on other water transport. The effects on marine *oil and gas extraction* have increased sharply in scale in recent years because of the intensification of development of oil and gas fields on continental shelves. Generally, these effects are caused by the *following*: (1) impact force; (2) splash on the structures; and (3) local erosion.

The loads caused by the *dynamic action* of storm waves are commensurable with those of ice fields on

Photo 4.30 Waves not only speed-down ships, but they also can damage or even destroy them. Another impact of waves on ships is pitch and roll, which causes discomfort to crew and passengers and spoils susceptible cargo. The photo shows waves in the coastal area near the mouth of the Columbia River, Oregon (United States) (Photo credit: U.S. National Oceanic and Atmospheric Administration, winter 1989)

Photo 4.31 One of the ways to protect dwellings and industrial structures from dynamic impact of waves is to make the first floors of buildings maximally open. The photo shows a house on the eastern coast of Texas (United States) that was built according to rules of anti-wave protection (Photo credit: H. J. Walker, March 1980)

marine stationary platforms. Under the action of waves, vibrations are initiated that create discomfort for the maintenance staff of marine platforms. The *splash* of waves to the support portion of a platform determines the safe elevation of the platform above sea level. *Bottom washout* around platform supports is especially dangerous in the shallows. The great lateral dimensions of these structures result in disturbances in the wave kinematics. These disturbances can cause extensive local bottom washouts that result in serious losses of overall stability of structures and even in accidents (Khalfin 1990).

Wind-generated waves are essential to *recreational activities*. Specifically, they are necessary for windsurfing, a variety of sailing sport in which a participant rides the waves on a light plastic board equipped with a sail.

The effects of wind-generated waves on human activities are illustrated by Photos 4.28–4.31.

4.10.2 Internal Waves

Internal waves are oscillatory motions of water that are initiated at the interface of water layers with different densities. Sea internal waves can be observed as frequently as those on the surface, and their motion runs through the whole column of the world's oceans.

The necessary *condition of initiation* of sea internal waves is the stable stratification of the water column provided by things such as atmospheric precipitation to the ocean surface, the presence in water of different suspensions, and surface heating by solar radiation.

The *formation* of internal waves also can be related to additional *factors* (Kononkova and Pokazeev 1985; Short-period internal waves in the upper ocean layer 1988; Gevorkyan 2000): (1) tangential wind action; (2) variations of atmospheric pressure; (3) resonant interaction of surface waves; (4) instability of large-scale currents with vertical velocity shear; (5) stratified flow around ocean floor irregularities; (6) tidal oscillations; (7) shift of ocean floor sections by seaquakes; (8) eruptions of undersea volcanoes; and (9) underwater landslides and mudflows.

The *parameters* of internal waves vary within a very wide range. High-frequency internal waves with periods of 5–10 min to 2–5 h have lengths of several hundred metres to some kilometres and propagation velocities of up to some tens of centimetres per second, and their amplitudes reach 10–20 m (Gevorkyan 2000). Low-frequency internal waves are characterized by periods of 8–12 h, lengths of tens and hundreds of kilometres, traverse velocities of several metres per second, and heights that may reach 100 m (Grue et al. 1999).

The *strongest* internal waves are related to tidal motions. Enormous internal waves appear permanently in the Straits of Gibraltar where the currents moving from the Atlantic Ocean to the Mediterranean Sea and back collide. By virtue of its higher salinity, the denser Mediterranean water moves nearer the floor while the less dense Atlantic water travels within the surface layer. Along the boundary of these countercurrents, an internal wave excited by the tide-generating forces propagates. On average, the height of this wave exceeds 50 m, while at the entrance of the Straits of Gibraltar, it reaches 85 m (Gevorkyan 2000).

The *regions* of the highest waves (100 m and more) are the southern tropical area of the Mid-Atlantic Ridge, the area off the Nova Scotia peninsula (southeastern Canada), and around the Mascarene Ridge in the Indian Ocean (Morozov 1985).

Internal waves *mainly affect* water transport and military activities. The effects on *water transport* are observed when the internal waves appear on the ocean surface or in immediate proximity to it. Such events are called the '*dead water*' phenomenon. In the vicinity of estuaries, the freshwater layer often lies above the layer of much saltier seawater. When the thickness of the freshwater layer corresponds approximately to a ship's draught, her propeller screw at low speeds can excite internal waves. In this case, energy that is ordinarily spent on the ship's motion is applied instead to the generation of internal waves, and the ship remains motionless (Monin and Krasitsky 1985).

Navigators of past centuries have time and again encountered this mysterious phenomenon in many regions of the Earth: Norway coast, Mediterranean Sea, Gulf of Mexico, and estuaries of large African rivers. One Scandinavian storey gives an account of a naval campaign of the Vikings that was interrupted at the pleasure of the gods. A large sailing-rowing boat could not leave a fjord in spite of the efforts of warrior-rowers (Mezentsev 1988).

On a trip to the North Pole in 1893, the Norwegian polar researcher Fridtjof Nansen encountered the 'dead water' phenomenon. Not far from the Taymyr Peninsula

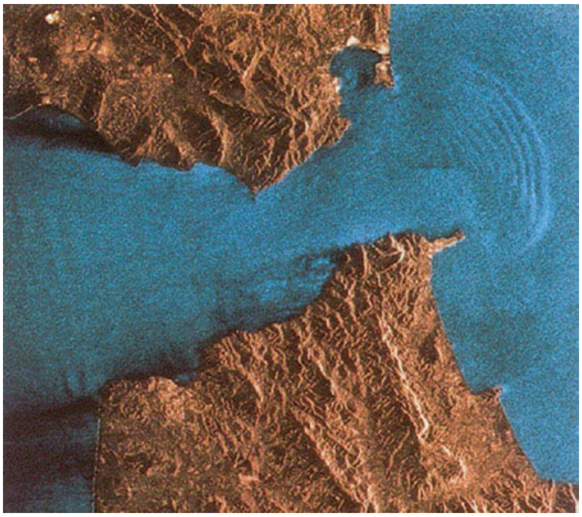

Photo 4.32 The Strait of Gibraltar is where currents moving from the Atlantic Ocean to the Mediterranean Sea and back collide. Along the boundary of these countercurrents, an internal wave excited by the tide-generating forces propagates. On average, the height of this wave exceeds 50 m, while at the entrance of the Straits of Gibraltar, it reaches 85 m. This image was created by overlaying three radar images taken on 12 August 2010, 1 October 2009, and 27 August 2009. Changes occurring between the times the images were taken became visible in different colours (Photo credit: European Space Agency)

(Russia), when the ship *Fram* approached the ice edge, it suddenly stopped moving although the engine was working at capacity. For several hours, the ship could not leave the small area covered by 'dead water' (Gevorkyan 2000).

The effects on *navy vessels* are similar to those on civil vessels. Internal waves represent a considerable danger for submarines. If it is in the layer of *less* dense water, a submarine can simply fall to deep layers, where it will be crushed by the water column. There is a theory that internal waves alone caused the loss on 10 April 1962 of the nuclear-powered submarine *Thresher* off the Nova Scotia peninsula. It is assumed that, as a result of collision with a great internal wave and due to its neutral buoyancy, the submarine slid downward to depths exceeding the maximum permissible (360 m) and was crushed. It is known that the submarine sank to the bottom, at a depth of 2,800 m, and that 129 people were killed (Zalogin and Kuzminskaya 2001; http://en.wikipedia.org/wiki/USS_Thresher_(SSN-593)).

The effects of internal waves on human activities are illustrated by Photo 4.32.

4.10.3 Seiches

A *seiche* is a standing wave that arises within a closed or partly closed water body. *Seiche* is a French word meaning 'wiggle'.

Seiches are *most characteristic* of the Great Lakes, the southern North Sea, part of the Mediterranean Sea between Sicily and Africa, the Baltic and Adriatic Seas, coastal waters off southern Sakhalin Island, the Gulf of Mexico, the Aral Sea, and Lake Geneva.

Wind is a major factor in seiche *formation*. The *second* most important cause of seiches is variations in atmospheric pressure. *Other factors* resulting in the formation of seiches include atmospheric fronts (i.e. air waves), sea internal waves, earthquakes and tsunamis caused by them, tides, volcanic eruptions, landslides, intensive precipitation within a part of the water body, and uneven distribution of electrical attraction between the water surface and passing thunderclouds (Geographical encyclopaedic dictionary 1988; Korgen 1995; Ecological encyclopaedia 1999; de Jong et al. 2003).

Let us consider the *generation mechanism* of wind seiches. Under prolonged wind action over a water body, there is wash to one of the shores. After the wind drops or reverses, the water, due to differences in levels, converges to equilibrium. As inertia is high and friction is insufficient to stop the movement of the water, the water mass is displaced farther and takes an oppositely directed incline. As before, gravity smoothes out a new incline. Similar variations can last for many hours and even days (Korgen 1995).

All water bodies with closed coastlines are favourable for the *initiation of seiches,* and, therefore, they are characteristic of lakes. As the waves are most effectively reflected from fixed, solid, and vertical boundaries, seiche are formed most commonly in water bodies with steep, rocky shores (Giese and Chapman 1993).

The *heights* of seiches are generally 20–30 cm; however, the maximum values are much higher. For example, they reach 250 cm in Lake Erie, 187 cm in Lake Geneva, and 162 cm in the Aral Sea (Ecological encyclopaedia 1999). The *periods* of seiches vary from several minutes to tens of hours, and they depend on the factor causing them, the size of the water body, and other factors. For example, seiches usually have periods of 30 min in the Rotterdam harbour (de Jong and Battjes 2004), 50 min in the coastal areas of Puerto Rico, 77 min off the Philippines (Huthnance 1989), but

Photo 4.33 Seiches occur on the Great Lakes every day. Sometimes they may be dangerous. This photo shows embankment in Canal Park in Duluth, Minnesota (United States) (Photo credit: Jeff Gunderson, Minnesota Sea Grant, 27 November 2001)

Photo 4.34 This photo was taken minutes apart (Photo credit: Jeff Gunderson, Minnesota Sea Grant)

21 h and 30 min in the Aral Sea (Ecological encyclopaedia 1999).

Seiches sometimes result in loss of life. They *create difficulties* for water transport, military activities, marine oil and gas extraction, and divers' work. *Dangerous seiches* are regularly formed off the southeastern shore of Lake Michigan, near Chicago. In this region, they constitute a threat to human life. For example, on 26 June 1954, a great seiche killed eight fishermen, whose bodies could not be found (Korgen 1995).

The effects of seiches on *water transport* are generally observed within harbours. They are caused by *three factors*: (1) abrupt vertical oscillations of the water level; (2) short-period horizontal motions of water masses; and (3) strong and unpredictable currents produced by seiches. In particular, seiches create serious difficulties at the port of Rotterdam. During the period 1995–2000, seiches were recorded there 49 times (de Jong and Battjes 2004).

Abrupt variations in water levels result in the *suspension of ships* moored at docks. Lake seiches can occur very quickly: on 13 July 1995, a big seiche on Lake Superior caused the water level to fall and then rise again by 1 m (3 ft) within 15 min, leaving some boats hanging from the docks on their mooring lines when the water retreated (http://en.wikipedia.org/wiki/Seiche).

The consequences of short-period horizontal motions of water masses involve *difficulties in manoeuvring*, *damage to moored ships,* and collisions of ships. One example is the loss of a ship staving in and sinking at a berth in Naples (Arsenyev and Shelkovnikov 1991).

The strong, unpredictable currents generated by seiches cause changes in the course of ships, their removal beyond the fairway, and grounding. The joint action of all three factors is called *harbour oscillation,* meaning the resonance wave oscillations of water (in the form of horizontal and vertical motions with a period of 0.5–4.0 min) in ports, bays, and harbours.

Harbour seiches can cause a ship to fall foul of the berth or neighbouring ships or abrupt repulsion of a ship from the moorage wall. During harbour seiches, the rhythmic operation of ports is disturbed. The pick-and-place operations are hampered, and demurrage of ships results in extensive losses for the maritime fleet.

The effects of seiches on *military activities* are similar to those on other water transport. In addition, seiches and the related harbour oscillations create considerable difficulty for the *landing of troops*. Moreover, the illumination of coastal waters by bioluminescent organisms disturbed by seiches can reveal the presence of people and vessels when a blanket of darkness is needed (Korgen 1995).

Seiches influence the *extraction of oil and gas* from lake and sea bottoms. They cause vertical oscillations of the ice cover, causing the under-stressed supports of oil and gas production platforms and hydraulic structures to be 'jacked' upward time and again every winter. The net upward motion of supports results from the fact that the resistance to upward motion is less than that to downward motion (Dynamics of snow and ice masses 1985).

Seiches often complicate a *diver's work*. Seiches roil the bottom sediments, thereby worsening, the visibility for divers. In addition, the suspension produced by a seiche may coat equipment, tools, and other things left at the bottom.

The effects of seiches on human activities are illustrated by Photos 4.33 and 4.34.

4.11 Glaciers

Glaciers are mobile natural accumulations of atmosphere-produced ice on the Earth surface. Glaciers occur on every continent and in approximately 47 countries (http://en.wikipedia.org/wiki/Glacier). They occupy an area of about 16.2 million km^2 (Fig. 4.9); that is, 10.9% of the land surface (Atlas of snow and ice resources of the world 1997, vol I, Book 2).

According to their *forms*, three classes of glaciers have been identified (Atlas of snow and ice resources of the world 1997, vol II, Book 1): (1) ice sheets (entirely cover the land and, sometimes, an offshore strip); (2) ice caps (cover the land by 30–40%; generally, they have a common feeding area, while the discharge area is divided into several isolated sections); and (3) mountain glaciers (form depends on the geological relief where they are located), which are *subdivided* into glaciers of heads, slopes, and valleys.

There are two major *mechanisms of motion* of glaciers: (1) creeping (ice moves due to visco-plastic deformation), and (2) sliding down along the bed and sides (facilitated by the formation of a water film produced by frictional heating or geothermal flow). Such water 'lubrication' decreases the friction factor ten times and more. Sliding may account for from 0% to 90% of the total velocity of a glacier; however, both mechanisms often make approximately equal contributions (Glaciological encyclopaedia 1984).

The *velocities* of glacier movement differ markedly. The velocities of small mountain glaciers are generally several metres a year. As to the great valley glaciers, their velocities reach 1,400 m a year (Dynamics of snow and ice masses 1985). The *fastest* in the world is Jakobshavn Isbræ in West Greenland. At its front end, velocities of up to 10 km/year have been recorded (Patterson 1984). The *maximum velocities* are characteristic of the central parts with gradual decreases in velocity toward the glacier ends and sides (due to glacier friction against the valley bed and sides) (Dolgushin and Osipova 1989).

In any glacier, one can identify two *zones*: (1) feeding zone, in which mass is accumulated, and (2) ablation zone, where the glacier mass decreases. The line dividing the feeding areas with positive and negative

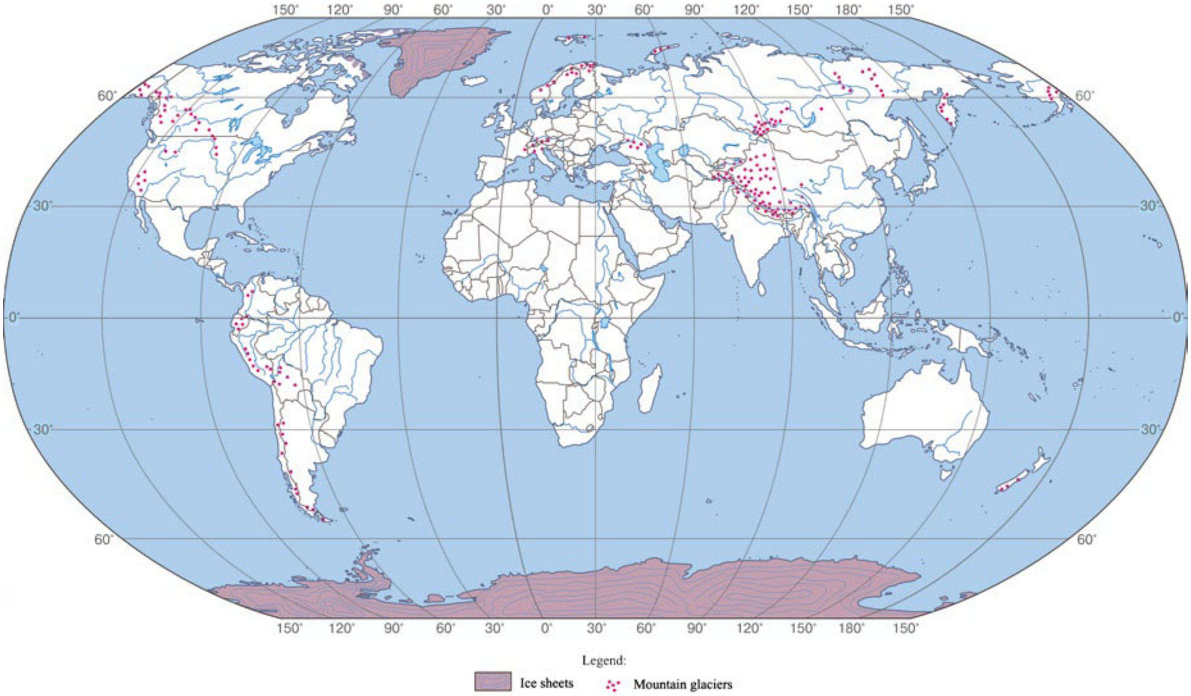

Fig. 4.9 Global distribution of glaciers (Resources and Environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of the Sciences)

annual balances of mass is called a feeding boundary. The *mass of a glacier decreases* as *follows*: (1) thawing; (2) evaporation; (3) blowing of snow by the wind; (4) glacier collapses; and (5) detachment of icebergs.

When a glacier moves, *bedrock failure* takes place that is related to *two mechanisms*: (1) detachment and breakout of fragments and (2) abrasion of the bedrock. The *first mechanism* occurs because ice sliding along the bed freezes periodically to it and entrains the rock pieces. The *second mechanism* involves grinding of the bed as fragments of firm rocks are entering into the composition of the ground moraine.

The *erosion rate* related to the movement of glaciers reaches 4–6 mm a year (Glaciological encyclopaedia 1984). The ice sheets of the northern hemisphere carry 0.47 billion tons of solid substance to the ocean every year. The transfer by Antarctic glaciers is much more – 1.92 billion tons (Yasamanov 2003).

Actually, all glaciers release a certain amount of *meltwater*, which can form when both surface horizons and bottom layers thaw due to friction of the glacier against the bed. The amount of meltwater is generally 1–2% of the glacier mass. The total *ice run-off,* equal to 3,450 km³ of water, is about 8% of the cumulative run-off of the surface waters to the ocean (Atlas of snow and ice resources of the world 1997, vol II, Book 1).

In some regions, glaciers are of paramount importance in the *feeding of rivers*. In essence, they are storage reservoirs accumulating moisture in the solid phase and returning it in summer (Patterson 1984). Among the rivers with great shares of *ice run-off* are the Terek (11%), Kuban (6%), Indus (8%), Syr Darya (6.5%), Amu Darya (15%), Tarim (30%), Yukon (23%), Kuskokwim (19%), Susitna (38%), Copper (19%) and Nass Rivers (27%) (Atlas of snow and ice resources of the world 1997, vol II, Book 1).

Quite often, glaciers are a cause of *floods*. The most typical case is when they block outer valleys. As a result of the appearance of a dam, a lake is formed. However, the ice dams are short-lived and break quickly. The Mertsbakher Lake in the Central Tien Shan breaks every year in August–September and, at that time, the volumes of glacier outburst floods reach 120–220 million cubic metres. Of special note is *jökulhlaups*, floods caused by the eruptions of volcanoes under glaciers or close to them. This phenomenon is

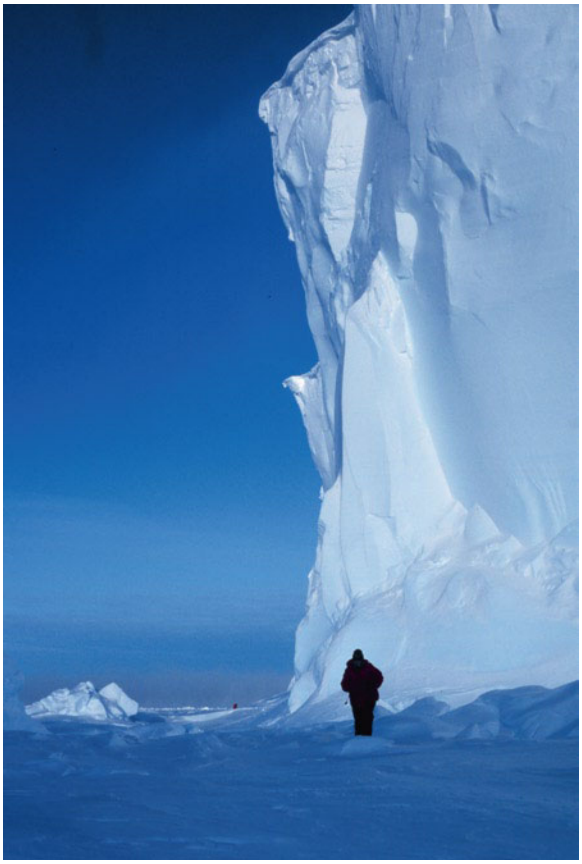

Photo 4.35 Ice sheets in Antarctica entirely cover land, as well as, sometimes, coastal waters. The photo shows the brim of the Ross Ice Shelf. It is the very place from which R. Amundsen started his successful journey to the South Pole (Photo credit: Michael Van Woert, U.S. National Oceanic and Atmospheric Administration, January 1999)

characteristic of Iceland. The jökulhlaups of the Vatnajökull-Gletscher above the Grímsvötn volcano are best known. Here, the volumes of glacier outburst floods reach 7 km³ (Vinogradov 1980).

Glaciers have a direct or indirect effect on people and many objects and *kinds of human activity* (Govorushko 2006b): (1) residential construction; (2) transport; (3) bridges; (4) crop production; (5) livestock farming; (6) water power engineering; and (7) the mineral resource industry.

The *major type of event* having direct effects on people is collapses – one-time falls of considerable ice masses, which happen when glaciers are at the top of steep mountainous slopes and over precipices. The greatest collapses are observed in such mountain regions as the Himalayas, Karakoram, Pamirs, and Andes (Geocryological dangers 2000).

The Mattmark glacial catastrophe on 30 August 1965 in Switzerland is widely known. A block of ice with a volume of about one million cubic metres separated from the Allalin glacier tongue and slid down along a slope of 27° over a distance of 400 m in the vertical. Then it moved inertially 400 m along the flat bed of the Saas Valley, killing 88 people engaged in the construction of a dam (Retlisberger and Casser 1978).

The indirect effects are mainly related to the formation of glacial lakes, which inevitably break, resulting in catastrophic floods. For example, in Peru in 1941, 6,000 people perished when a glacial lake suddenly burst open, flooding the town of Huaraz below it (Kotlyakov 1994).

The effects on *residential construction* are caused by both catastrophic factors (breaks of glacier-dammed lakes and falls of ice) and slow motion of glaciers when they demolish buildings and other structures. For example, in the course of glacier contraction in Iceland and Greenland, the ruins of Viking structures have been found (Mezentsev 1988).

The influences of glaciers on different kinds of *transport* are related to such events as ice falling, breaks of glacier-dammed lakes, and burial under the ice mass. An example of the effect of *ice falls* is the 'Kazbek obstructions' – collapses of the Devdoraksky Glacier blocked the Georgian Military Road in the eighteenth and nineteenth centuries (Myagkov 1995). George Lake in Alaska is an example of the impact of *glacial lakes*. The catastrophic floods that occur when it breaks periodically wash down the Anchorage-Palmer highway and the Alaska Railroad (Kotlyakov 1994). *Burial with ice masses* occurs as glaciers advance. Now, as a result of reduction in the areas of Alpine glaciers, roads cobbled by the Romans are being revealed (Mezentsev 1988).

The effects on *bridges* are related to breaks of glacier-dammed lakes. For example, a catastrophic flood that happened on 10–11 January 1934, on the lake dammed by the Nevado Glacier in Argentina, destroyed seven bridges (Vinogradov 1980). The influence on *crop production* and *livestock farming* is caused by breaks of lakes and advance of glaciers. The Moreno Glacier streaming down from the south Patagonia glacial field regularly blocks the great Argentino Lake (Lago Argentino), cutting off a very large bay of the lake from the remaining water. During the period 1934–

Photo 4.36 Mountain glaciers are distinguished by their variety. Their shapes depend on the structure of relief where they are situated, especially on such details as summits, slopes, and valleys. The photo shows the Findelen valley glacier, located on the northern slope of the Panin Alps, Switzerland. The photo was taken at an altitude of 3,500 m (Photo credit: S.M. Govorushko, 3 September 2006)

Photo 4.37 Glaciers tend to gradually change in size. The photos of Aletschgletscher in the Alps were taken from one position, in 1979 (*left*), 1991, and 2002 (*right*) (Photo credit: L. Albrecht, http://en.wikipedia.org/wiki/File:Gletscherschmelze.jpg)

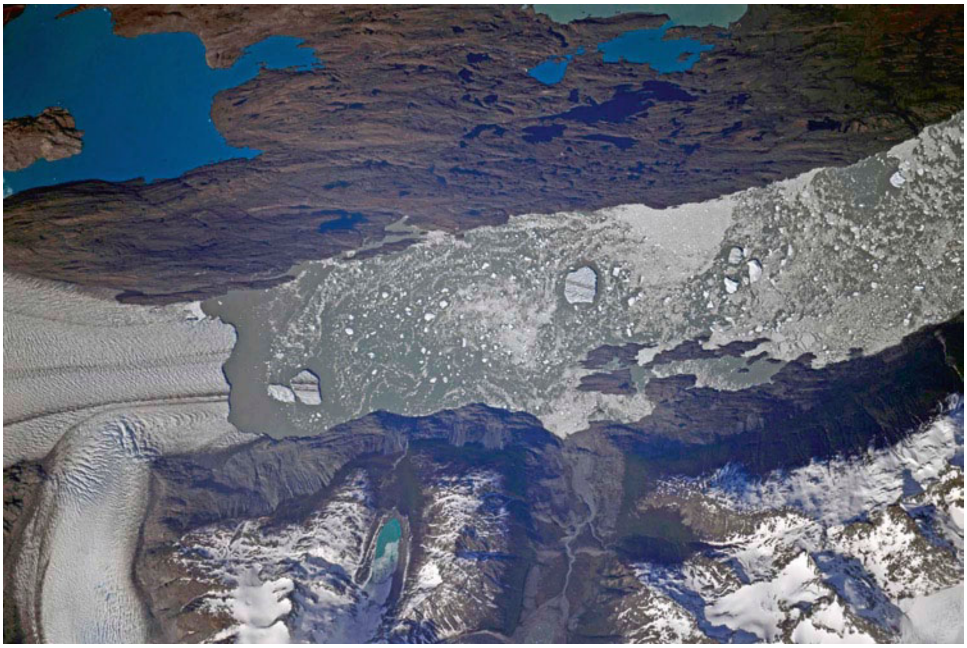

Photo 4.38 One of the indirect effects of glaciers on human activities is the production of icebergs. This detailed space photograph shows icebergs that were calving from the Upsala Glacier terminus into the waters of Lago Argentino (Photo credit: Russian Space Agency)

1958, this phenomenon was observed nine times, and the water level within the cut-off bay rose from 6 to 30 m. Every time, it flooded some thousand hectares of tilled lands and pastures (Kotlyakov 1994).

The advance of glaciers sometimes buries *farms* and *fields*. This phenomenon was widespread in Iceland during the period 1712–1760 (Dolgushin and Osipova 1989). The destruction by the Nigardsbreen Glacier of potato fields in Norway in the mid-eighteenth century was described by V.M. Kotlyakov (1994). The *positive effect* of glaciers on agriculture is related to their considerable contribution to the nourishment of rivers. This influence of glaciers is especially favourable in the countries of central Asia and in the Canadian prairies (Patterson 1984).

The effects of glaciers on *water power engineering* may be either negative or positive. The *negative* influence is related to the powerful destructive effect of glacier collapses; in part, the burst waves caused by them are very hazardous for hydraulic structures (Atlas of snow and ice resources of the world 1997, vol II, Book 2). However, the *positive influence* on power engineering predominates, and it is related, first of all, to the great contribution of glacier meltwater in the nourishment of rivers where hydropower stations have been constructed.

The effects on the *mineral resource industry* may be caused by different factors. An event when glacier motion threatened a copper-ore mine in western Canada has been described by U.S.B. Patterson (1984). In 1963, the entrance to the mine was 19 m above the ice surface near the glacier end. If the former rates of motion had been maintained, ice should have reached the entrance to the tunnel by 2003. However, the speed of the glacier slowed, which delayed the crisis situation beyond the operational life of the mine.

The effects of glaciers on human activities are illustrated by Photos 4.35–4.38.

Photo 4.39 One of the typical consequences of glacier surging is the formation of glacier-dammed lakes. Each movement of the Medvezhy Glacier led to the formation of Abdukagor Lake. The speed of the glacier movement was from 12 to 100 m/day. The photo shows the initial stage of the lake formation (Photo credit: L.V. Desinov, Institute of Geography, Moscow, Russia, 24 July 1989)

4.11.1 Surging Glaciers

A *surging glacier* is a glacier that is subject to periodic abrupt motions (surging). According to S.M. Myagkov (1995), they include not less than 5% of all glaciers in the world.

As to *mountain territories,* the maximum prevalence of surging glaciers is characteristic of the Pamirs, Tien Shan, and Karakoram. In the Pamirs, 845 surging glaciers have been found, which is about 11% of the total number of glaciers in that mountain range (Osipova et al. 1998). On the other hand, no authenticated cases of surging of present-day glaciers have been recorded in Scandinavia, Dzungarian Alatau, the Ural Mountains, the Altai Mountains, the Suntar-Khayata Ridge (Dolgushin and Osipova 1982), or the Alps (Patterson 1984).

The *causes* of glacier pulsations are as yet unknown. Glacier pulsations are a periodic phenomenon with a more or less constant cycle for every glacier. However, different glaciers, even though they are under the same physico-geographical conditions, have absolutely different periods of pulsations (i.e. time intervals between motions), which can vary from several years to a hundred or more.

The *period of pulsations* includes two major *stages*: (1) motion and (2) restoration. At the *first stage*, there is a release of stresses accumulated in the glacier; it cracks

Photo 4.40 The impact of the Kolka surging glacier on dwellings during the surge of 20 September 2002 resulted in both destruction of buildings due to dynamic impact of ice and debris and their further inundation by melted ice. The photo shows a few intact buildings in the Nizhniy Karmadon settlement. Most buildings were destroyed, and more than 100 people were killed by the glacier (Photo credit: L.V. Desinov, Institute of Geography, Moscow, Russia, 22 September 2002)

and ice motion speeds increase by 1–2 orders of magnitude (i.e. 10–100 times) and more. The *restoration stage* comes upon completion of the motion stage. At this time, there is an accumulation of ice mass in the upper part of the glacier, until the glacier restores its initial configuration (Glaciological encyclopaedia 1984).

The pulsation period *duration* depends on the mass of ice displaced in the course of motion and ice accumulation rates during restoration. For example, an ice mass of 160–180 million tons is critical for Medvezhy Glacier (the Pamirs); therefore, if the yearly accumulation is 16–18 million tons, the pulsation relaxation occurs in 10 years, while for an increment of only 11–12 million tons, it occurs in 15 years (Atlas of snow and ice resources of the world 1997, vol II, Book1).

The *durations* of motion in different surging glaciers differ substantially. For example, it lasted 3 months in Medvezhy Glacier and 5 years (1972–1977) in Sat Glacier (Zaalaisky Ridge in the Pamirs). On average, their duration is 1–2 years. Sometimes there is a transformation of the glacier motion (shift) into the ice flow-surge. In such situations, the pulsation lasts several minutes. Examples of this phenomenon include the motions (shifts) of Didal Glacier in the Pamirs in 1974 and of Kolka Glacier (Caucasus) in 1902 and 2002 (Atlas of snow and ice resources of the world 1997, vol II, Book1; Kotlyakov et al. 2003).

The *maximum recorded speeds* of glacier motion for some large glaciers of North America reach 120 m/day, while they average 15–16 m/day over the course of a year (Dolgushin and Osipova 1982).

The *formation of barrier lakes* is a typical consequence of glacier pulsations. Each pulsation of the Medvezhy Glacier results in the formation of the

Photo 4.41 The surge of the Kolka surging glacier on 20 September 2002 created an ice mass mixed with water and rock material that blocked a road in the valley of the Genaldon River, which leads to the Nizhniy Karmadon settlement and several resort areas (Photo credit: L.V. Desinov, Institute of Geography, Moscow, Russia, 21 September 2002)

Abdukagorsky glacier-dammed lake (Photo 4.39). In the Karakoram, the surging Chong Kumdan, Kichick Kumdan, and Aktash Glaciers, located in neighbouring outer valleys, block in turns in the Shyok River valley, forming lakes (Atlas of snow and ice resources of the world 1997, vol II, Book 1).

In some cases, surging glaciers cause *numerous casualties*. They also influence many economic entities and *kinds of human activity*: (1) residential and industrial construction; (2) motor transport; (3) rail transport; (4) water transport; (5) bridges; (6) crop production; (7) livestock farming; and (8) transmission lines. The effects on economic activities are generally related to three *factors*: (1) ice pressure; (2) blockage with ice and sediment layers; and (3) breaks of glacier-dammed lakes.

As for *human mortality*, the most catastrophic consequences have been characteristic of the motions of the surging glacier Kolka in Caucasus. In the summer of 1902, several dozen people were killed (Kotlyakov 1994). One hundred years later, on 20 September 2002, the number of dead was 125 persons (Poznanin and Gevorkyan 2007). Sometimes, catastrophic floods after the breaks of glacier-dammed lakes result in great numbers of victims.

The effects on *industrial and civil engineering* are related to both ice pressure and breaks of glacial lakes. The consequences of glacier pulsations are in many respects determined by the extent of development in a region. Numerous motions on Spitsbergen Island caused the destruction of only a hut after the Marmorbreen Glacier surge in 1897. Later, a surge of the Kutyakh Glacier in Karakoram in March 1953 destroyed several structures (Dolgushin and Osipova 1982). Then, on 20 September 2002, a catastrophic surge of Kolka Glacier demolished the settlement of Nizhny Karmadon and several resorts (Kotlyakov et al. 2003).

The influence on *motor and rail transport* is related both to blockage of roads with the sediment mass and breaks of lakes. For example, the activation of Black

Rapids Glacier in Alaska was observed in September 1936. By February 1937, the glacier tongue had advanced a distance of 6.5 km and threatened to cut off the only highway at that time connecting Fairbanks with the remote region (Kotlyakov 1994).

An example of the influence on *rail transport* is the motion (pulsation) of Nevado Glacier on the east slope of the Andes very late in 1933. After 50 years of quietude, the glacier caused a blockage of Rio Plomo. The lake that formed, which was 30 m deep, drained on 10–11 January 1934, and the intensity of flow reached 3,000 m³/s. As a result of the flood, 13 km of the Transandine Railway passing through the Mendoza canyon and Cumbre tunnel between Argentina and Chile were destroyed (Vinogradov 1980).

The effects on *water transport* include blockage of bights and fjords as well as the production of large numbers of icebergs, creating difficulties for navigation. Examples of such effects include the motions of surging glaciers in Spitsbergen (Hays-Gletscher Glacier in 1901, Negribreen Glacier in 1932–1935, and Brasvellbreen Glacier in 1936–1938) (Atlas of snow and ice resources of the world 1997, vol II, Book 1).

The destruction of *bridges and transmission lines* occurs due to the ice mass pressure and also as a result of breaks of glacial lakes. The influence on *crop production* and *livestock farming* does not in essence differ from that of normal glaciers.

The effects of surging glaciers on human activities are illustrated by Photos 4.39–4.41.

4.12 Rock Glaciers

A *rock glacier* is an accumulation of rock material cemented (consolidated) with ice. *Two categories* of rock glaciers have been identified: (1) ice-cemented rock glaciers (cryogenic formations having no historico-genetic relation with glaciers) and (2) ice-cored rock glaciers (formed from glaciers in the course of their reduction and burial under layers of detritus).

Ice-cored rock glaciers are more numerous, and sometimes it is quite difficult to distinguish between a glacier and a rock glacier. For example, based on detailed study of structure, mass exchange, and dynamics, many glaciers in the Alps have been determined to be rock glaciers (Krainer et al. 2002).

For the terrestrial globe as a whole, areas occupied by rock glaciers are much smaller as compared with those occupied by glaciers. With respect to glaciers, rock glaciers occupy a *lower hypsometric position* (Galanin 2005).

Rock glaciers are characteristic of many mountain systems with cold and moderately humid climates (Fig. 4.10). They are *abundant* in the Alps, Caucasus, Pamirs, Hindu Kush, Tien Shan, Karakoram, Rocky, and Andes Mountains, and in Greenland, Spitsbergen, New Zealand, and coastal areas of Antarctica (Gorbunov 2008). Small rock glaciers also occur in the high mountain areas of Africa and Central America.

Disko Island, off the western coast of Greenland, can be called a real *kingdom of the rock glaciers*. Its area is 8,575 km², and its maximum height reaches 1,904 m. This island has about 1,700 rock glaciers (Gorbunov 2008). In north-eastern Russia, with an area of 1.57 million km², there are 6,500 rock glaciers (Galanin 2009). In the Swiss Alps, 994 active rock glaciers have been identified (Barsch 1996).

According to dynamic activity, the following *types* of rock glaciers have been identified: (1) active; (2) inactive; and (3) fossil rock glaciers (Barsch 1996). The drift *speeds* of active rock glaciers are, on average, several tens of centimetres per year. Speeds of some metres per year have been recorded in the Andes where there are abrupt increases in slope inclination (Kotlyakov 1994). Under certain conditions (for example, at seismic points), catastrophically fast drift of vast masses of ice-rock material is possible, such as that observed in the course of the Yamsky earthquake of 1851 in Priokhotye (Russia) (Galanin 2005).

As for the *sizes of rock glaciers*, their *lengths* vary from hundreds of metres to several kilometres, *widths* reach hundreds of metres and even kilometres, while the maximum *thickness* is about 100 m (Galanin 2008). Rock glaciers end in benches with heights of 15–50 m and sometimes up to 80–100 m.

Rock glaciers influence chiefly the following *kinds of human activity*: (1) transport; (2) water power engineering; (3) residential construction; and (4) the mineral resource industry.

The effects on *motor and rail transport* are related to the dynamic action of the rock-ice mass and blockage of roads with deposits. The influence on *water power engineering* is generally *positive* because of the considerable contribution of rock glaciers to the nourishment of rivers on which hydropower stations have been constructed.

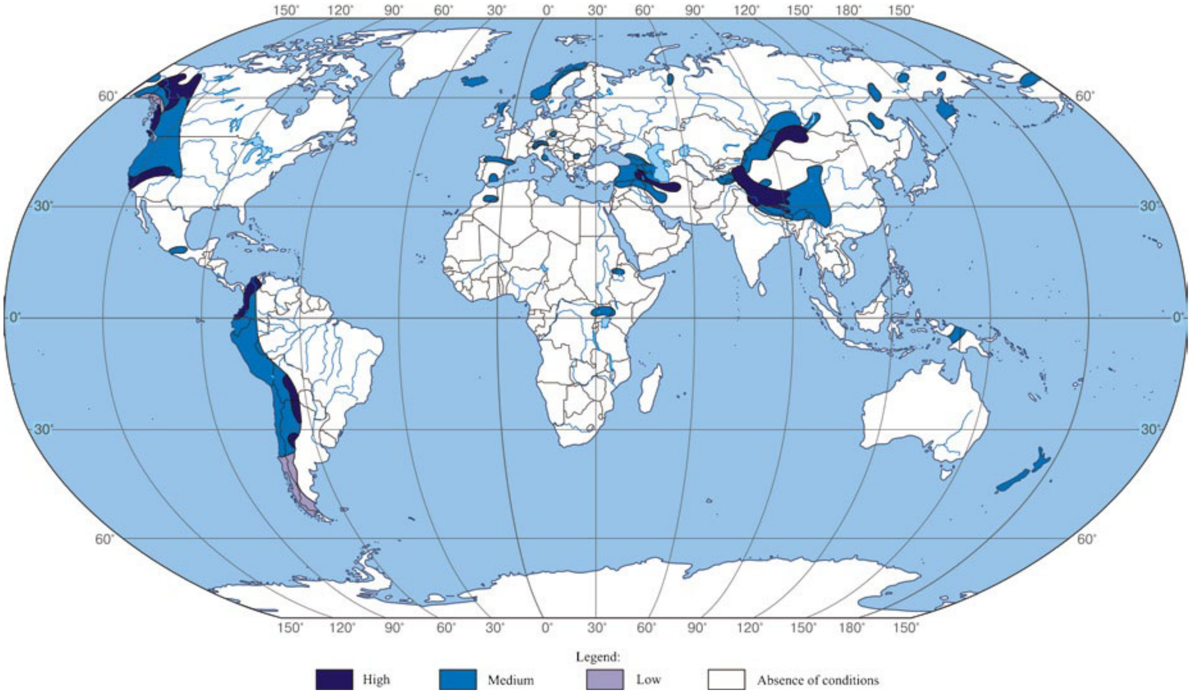

Fig. 4.10 The degree of favourable conditions for the formation of rock glaciers (Barsch 1996)

Photo 4.42 The impact of rock glaciers on human activities, generally, is not great. The photo shows the threatening movement of a rock glacier towards the Flüela Pass on the road connecting Switzerland and Italy. This pass is the watershed between the basins of the Rhine and Danube Rivers (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 28 August 2006)

The effects on *residential construction* are caused by both breaks of rock glacier–dammed lakes and their slow drift when they destroy houses and other structures. Examples of both types of events for the southern Chukot Peninsula are presented by A.A. Galanin (2005). He notes a great lake dam near the settlement of Provideniya, as well as the danger posed by rock glaciers to several buildings in the settlement of Ureliki.

The effects of rock glaciers on the *mineral resource industry* include creating difficulties for mining operations through the blockage of corrals, filling of open pits with rock-ice masses, and other problems.

The effects of rock glaciers on human activities are illustrated by Photo 4.42.

4.13 Variation of Non-draining Lake Levels

A *non-draining lake* is a lake having no surface or underground outflows. The largest non-draining (closed) lakes include the Caspian and Aral Seas; Lake Balkhash, Lop Nur, Lake Rizaiyeh (Lake Urmia), Lake Van, and Lake Chany in Eurasia; Lake Chad, Lake Rudolf, and Lake Rukwa in Africa; Lake Eyre, Lake Amadeus, and Lake Torrens in Australia; and the Great Salt Lake in North America. Areas of internal drainage are shown in Fig. 4.11.

Fluctuations in water levels with different *periodicity* are peculiar to many non-draining (closed) lakes. Such lakes may be divided as *follows*: (1) lakes with seasonal fluctuations in water levels, including (a) yearly ephemeral lakes, (b) periodically ephemeral lakes, and (c) permanently existing lakes; and (2) lakes having level fluctuations that are characterized by much longer period, including (a) lakes in which water content changes are caused by periodic changes in the direction of currents in tributaries, (b) lakes in which level fluctuations are caused by climatic factors, and (c) lakes with level fluctuations that are related to other causes.

An example of a lake that *dries out every year* is provided by Lake Eyre, which fills with water only in summer; however, its area may reach 15,000 km^2, while its depths can reach 20 m. A lake that *dries out periodically* is Lake Torrens, which can sometimes cover an area of 8,700 km^2 at a depth of 8 m and dries up in some years. Lake Chad is a *permanently existing lake* with *considerable seasonal fluctuations* in water levels; for example, the water volume in May is only a fourth of the volume in autumn.

Among the lakes with water contents that fluctuate sharply due to *changes in river run-off to them* is Lop Nur in western China. Its level varies markedly from year to year due to migrations of the Tarim and Konche Darya riverbeds. When they fall into Lop Nur, the lake area may reach 3,000 km^2, whereas when these rivers flow instead into Kara-Koshun Lake, Lop Nur transforms into several smaller lakes.

The area of the Great Salt Lake in the United States varies between 2,500 and 6,000 km^2. This lake falls into the category of lakes in which oscillations in water levels are determined by *climatic variations*. Some lakes, including the Caspian Sea, Lake Chany, and others, are characterized by level oscillations the periodicity and mechanism of which remain *unexplained*.

The above subdivision of non-draining lakes is conditional; some lakes may simultaneously belong to two or more groups. For example, the level oscillations in Lake Chad have a seasonal character (the maximum level is observed after the summer rainy season), a 20- to 30-year periodicity (when the lake area varies from 1,350 to 26,000 km^2), and centuries-old cycles (for example, the area of the lake reached 400,000 km^2 5,000–6,000 years ago).

From the viewpoint of the *effects on human activities,* of prime interest are the sharp level variations that have been observed in recent times and that are still taking place. For example, reductions in levels during the period 1870–1970 reached 3.2 m in Lake Issyk Kul, 10 m in Lake Rudolf (Myagkov 1995), and 22 m in the Dead Sea during 1970–2006 (http://en.wikipedia.org/wiki/Dead_Sea). Among the lakes with sharp increases in levels are the Great Salt Lake, 2 m for 1983–1985 (Myagkov 1995), and Devils Lake (North Dakota, United States), 15 m during 1950–2010, including 8.5 m since 1993 (Zhang 2010).

However, the most dramatic consequences are characteristic of the *fluctuations in water levels in the Caspian Sea;* the reasons for these fluctuations have never been determined. It is the largest closed water body in the world. Now, its area is about 390,000 km^2, and the water volume is approximately 78,000 km^3; the average depth is 208 m, while the maximum depth reaches 1,025 m.

Quick *changes of levels* in this lake are by no means uncommon; this is a rather *ordinary state* for this water body. Five thousand years ago, the sea level exceeded

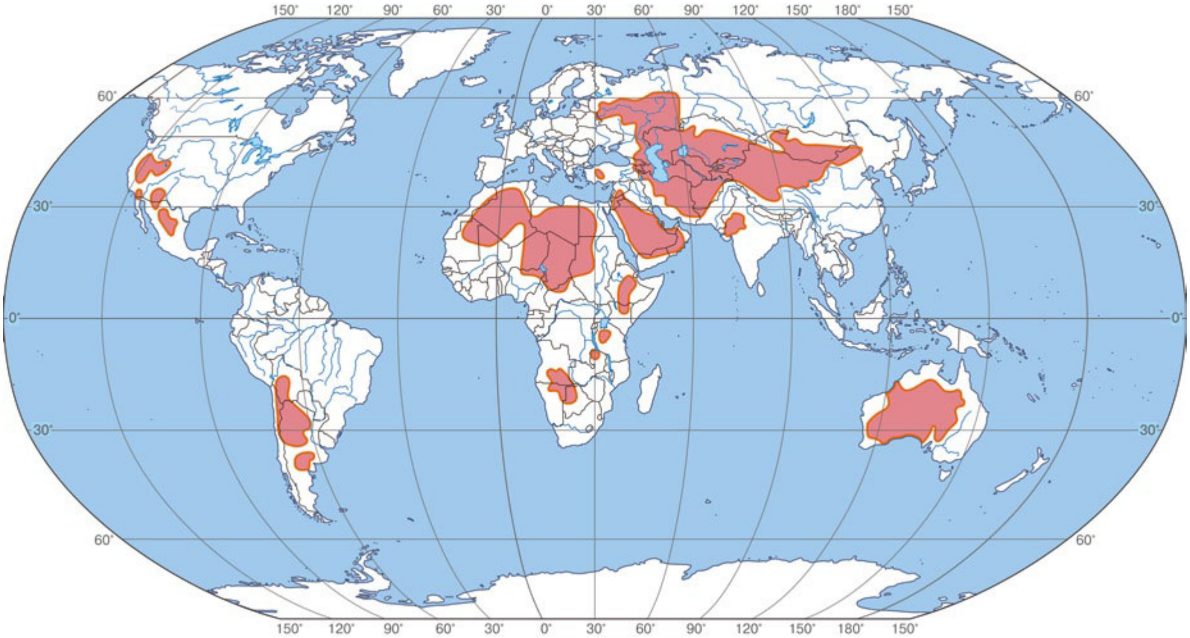

Fig. 4.11 Areas of internal drainage (Adapted from Global water balance 1974; Mikhailov et al. 2007)

Photo 4.43 Considerable fluctuations of water levels in the Caspian Sea are common for this water reservoir. During the period from 1883 to 1977, the water level there dropped 3.8 m. Later on, the waters began to rise, and by 2000 the water levels had risen by almost 2 m. Houses in Derbent (Russia) that collapsed as a result of the Caspian Sea level rise are shown (Photo credit: A.L. Ragozin, Institute of Geoecology, Moscow, Russia, 1994)

Photo 4.44 Analogous fluctuations are typical for the Aral Sea as well. The amplitude of fluctuations during the last 500 years constituted more than 50 m. To date, much evidence of ancient human activity – namely, millstones, bricks, fragments of crockery, and iron and bronze items – has been found at the bottom of the Aral Sea. The photo shows a burial place in a mediaeval town near Barsa-Kelmes Island. The town existed there for thirteen to fourteen centuries (Photo credit: I.S. Plotnikov, Institute of Zoology, St. Petersburg, Russia, 2004)

that of 1995 by 4.5 m, while 1,500 years ago, it was lower than it is now by 6.5 m (Svitoch 1997). During some periods, the level variations have been very quick. For example, during the period 1570–1640, it rose by 7.3 m (average rate was 10.4 cm/year). From 1883 to 1977, the level dropped by 3.8 m (Geoecological changes when the Caspian Sea level is oscillating 1997). In 1978, the Caspian Sea level began to rise. By 1995, it had increased by 2.35 m; the average rate was 13 cm/year (Dynamics and interaction of the atmosphere and hydrosphere 2004). This rise proved to be quite unexpected.

The level variations of closed (non-draining) lakes influence the following objects and *kinds of human activity* (Govorushko 2007d): (1) settlements; (2) crop production; (3) motor roads and railroads; (4) transmission lines; (5) oil extraction on land and the sea floor; (6) plant facilities; (7) water transport; and (8) fisheries.

The examples of influence on *population* are quite numerous and have taken place when a level is rising. The disaster that befell the Khazar Khaganate is the most striking of them. This state formed in the third century AD within deltas of the Terek and Volga Rivers, when the Caspian Sea levels were 8–9 m lower than they are now. In the eighth through ninth centuries, the Caspian level rose by 5 m and, by the fourteenth century, by another 3 m. Therefore, the civilization was destroyed after more than a 1000-year existence (Kurbatova et al. 1997).

Cases of influence on *individual settlements* are also well known. In 1871, the town of Nguigmi had existed for more than one century on the northern shore of Lake Chad; at that time, the town was flooded and demolished by the lake level rise. Several settlements dating back to the thirteenth through fifteenth centuries have been found at the bottom of the Aral Sea (Photo 4.44); the depth of the sea at the site of the settlements was about 20 m in the mid-twentieth century.

The effects on *crop production* are observed when the water level is rising. For example, 320,000 ha of arable lands on the Russian coast were flooded as a result of the Caspian Sea level rise during 1978–1995 (Vladimirov and Izmalkov 2000).

Photo 4.45 To what extent the Aral Sea is becoming shallower due to natural factors and to what extent due to human activities is debatable. Man obviously contributed to the process by diverting water from the Amu Darya and Syr Darya Rivers for irrigation needs. The photo shows vessels at the dry bottom of the Aral Sea (formerly the Bay of Zhalanash) (Photo credit: Zhanat Kulenov, UNESCO, 2006)

The impacts on *motor roads* and *railroads,* as well as on *transmission lines,* are observed as the level rises and structures are flooded. For example, the Astrakhan-Kizlyar railway and tens of kilometres of transmission lines were within the flooded area (Karabayeva 2002). To a considerable extent, the Caspian level fluctuations affect *oil production*. In particular, 15 *oil wells* located on the shore were flooded (Novikov 1999). The level rise also resulted in massive damage to *marine oil field structures* through two means: (1) increases in wave heights in connection with increases in depth; and (2) reduction in the distance between the decks of offshore platforms and the calm water surface. As a result, strong storm waves began not only to reach the tops of platforms but also to flow over them. In a number of locations, this caused a complete failure of oil field structures (Akhmedov et al. 1993).

The effects on *manufacturing facilities* are also related to flooding and waterlogging and also to direct wave action. The effects on *water transport* are observed in cases of level rise and recession. Recession results in the situation in which piers, berths, and other structures are on land, making it necessary to build them again. Increases in water levels cause flooding of harbour installations.

The influence on *fisheries* on the Caspian Sea is expressed as undermining of the sturgeon population, because as a result of drops in water levels, areas of shoaling waters (places of fry fattening) decrease sharply. Taking into account that the Caspian provides 80–90% of the world's catch of sturgeons, this effect could have global consequences if the drops in water levels continue (Bloom 1998).

The *economic consequences* of water level fluctuations in closed lakes are great. In the case of the Caspian Sea, the losses, according to different data, amounted to from US$6 billion (Caspian resists 2002) to US$15 billion during the last period of increasing levels (1978–1995) (Erdniyev 1999).

The effects of level fluctuations in closed lakes on human activities are illustrated by Photos 4.43–4.45.

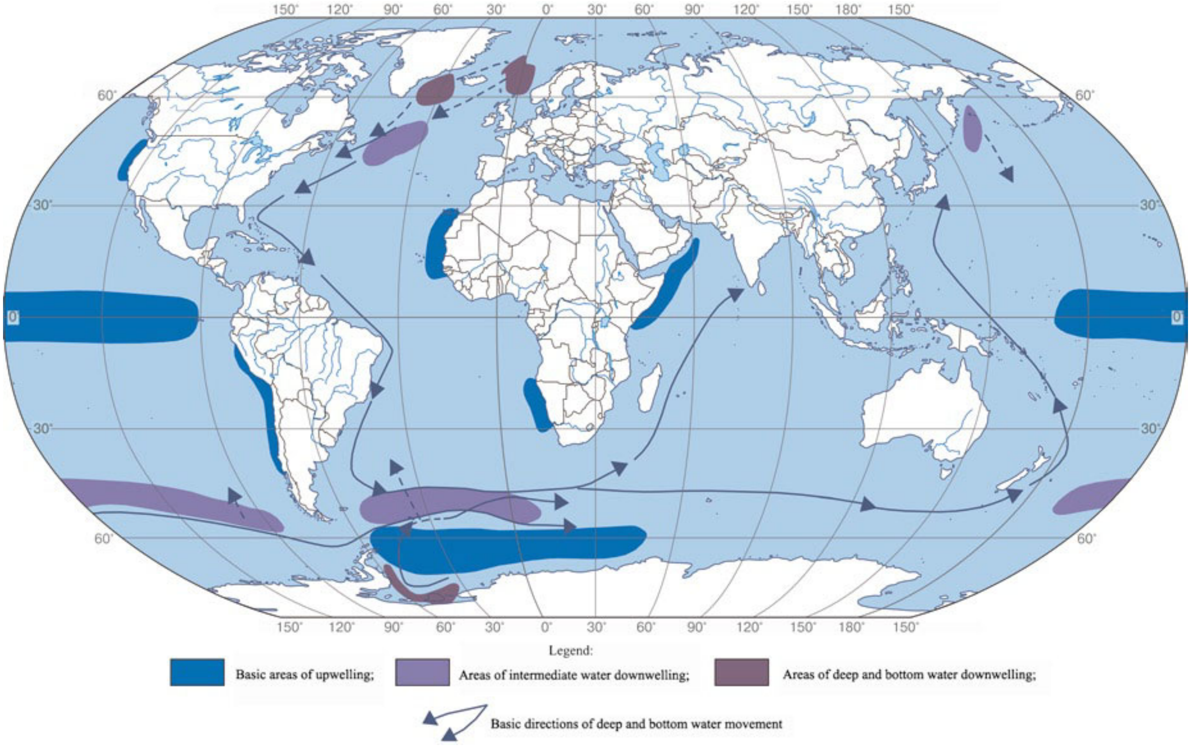

Fig. 4.12 Areas of upwelling and downwelling (Adapted from Neshyba 1991. http://www.geo.arizona.edu/Antevs/ecol438/lect15.html#04)

4.14 Upwelling and Downwelling

An *upwelling* is a rise of deep sea waters to the surface. Accordingly, a downwelling is a process in the opposite direction.

The *primary zones of upwelling* are located off the eastern boundaries of oceans. There are several stationary upwellings. Those in the Atlantic Ocean include the Canary (West African), Guinean, Brazilian, and South African upwellings. Those in the Indian Ocean include the Bengal and Somali upwellings. In the Pacific Ocean, there are the Chilean-Peruvian, Californian, and Oregon upwellings. There is upwelling in the Beaufort Sea (Arctic Ocean). On the whole, upwelling zones occupy 0.1% of the total area of the world's oceans (Neshyba 1991).

Basic areas of downwelling include the coastal waters of Antarctica (basically, the Weddell Sea) and the North Atlantic (predominately off the Greenland coast). The area of downwelling zones in the world's oceans is much smaller than that of upwelling zones, as the downwelling rates are always two to three times larger than upwelling rates (Monin and Krasitsky 1985). Areas of upwelling and downwelling are shown in Fig. 4.12.

For the most part, an upwelling arises due to *strong and long-lasting winds* that cause set-down of surface waters from the shore to the open ocean. The water level recedes near the shore and, to compensate, waters of deeper horizons rise to the surface. Other reasons are *currents* and *internal waves* (Zalogin and Kuzminskaya 2001).

The *initiation* of downwelling is related to increases in the specific weight of water, which may be caused by increases in salinity, drops of temperature, and other factors. The *most powerful downwellings* are the Greenland downwelling, which moves five million m^3/s of water, and the downwelling in the Weddell Sea, where about 25 million m^3/s of water move to the bottom (Neshyba 1991).

According to the requirement for *mass balance* between different ocean layers and zones, upwelling and downwelling are related to each other. Water descending at one place rises to the surface in another. For example, water descending off the shores of Greenland then moves as the North Atlantic deep water, and, after hundreds of years, it rises to the surface in the southern oceans.

Upwelling and downwelling are of importance for two *kinds of human activity*: (1) fisheries and (2) recreational activities.

The importance of upwelling for *fisheries* is great. The deep waters are very rich in biogenic matter (phosphates and nitrates). When they rise to the surface within the illuminated zone, the productivity of the water increases sharply, and it is favourable to phytoplankton growth. In turn, this favours the growth of zooplankton and the development of all subsequent links in the food chain, including fish. Upwelling zones provide a half of the fish catch (Gill 1986, vol 2). The most productive sections of the ocean are upwelling zones off the shores of Peru, Bengal (India), and the Canary Islands (Heinrich and Hergt 2003).

An upwelling has a certain effect on *recreational activities,* related to abrupt drops in the water temperature within the coastal zone. For example, short-lived wind-induced upwellings often arise in the Black Sea, decreasing the water temperature by 3–5°C (Zalogin and Kuzminskaya 2001). In July 2004, upwelling periodically (for 5–6 days) caused the water temperature to drop at the Black Sea health resorts of the Crimea and Caucasus to 13–14°C, with the result that the swimming season was practically ruined.

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5 Biological Processes

Abstract

Biology is a natural science concerned with the study of living organisms, including their coexistence in the environment. The habitats of humans and other living organisms coincide, and their activities influence one another. The value of other living organisms to human beings is immense, and without them, the existence of humanity on earth would be impossible. Indeed, we must remember that all nutrients (proteins, fats and carbohydrates) are derived from other living organisms, and our only inorganic foods are salt and water. This chapter focuses on species that have the most adverse effects (at some point through their life history) on human beings. Negative influences can be attributed to feeding activities, diverse defence actions, or just simply the struggle for coexistence with mankind.

Keywords

Biology • Animals • Plants • Microorganisms • Mortality • Economic loss • Damage • Biological processes • Rates • Origins • Impacts • Human activity

5.1 Agricultural Pests

Agricultural pests are animals that damage or kill plants. There are roughly 70,000 species of agricultural pests in the world (Pimentel et al. 1997). Most of them belong to the class of insects; some are ticks (or acarines), from the class of arachnids. Molluscs (phylum Mollusca) and worms (phylum Nematoda) also have some pests. Damage to cultivated plants can also be caused by larger animals such as birds and mammals, mostly rodents.

The *main reason* pests can have a harmful effect on agricultural plants is simple: pests host on plants. *Pests also damage* agricultural plants through *animal migration*, *nesting over planted fields*, or *embedding eggs in plant tissues*. Most commonly, plant tissues are damaged or destroyed by the feeding of *gnawing pests*. Damage to plant leaves leads to *shrinkage* of the assimilating surface area, while damage to stems *slows nutrition* and water delivery to other parts of the plant. Root damage *disturbs the absorption* of minerals and water from the soil. These negative effects weaken agricultural plants, slow down their growth and cause parts of plant tissues to rot.

In the majority of cases, *sucker pests* do not damage the apparent integrity of plants. They are generally first recognized on the surface of plants as spots, which are good indicators of pathological changes in the affected area. Sucking pests inject their salivary gland secretions into plant tissues, which leads to biochemical changes in the plant cells and tissues. Aphids (Aphidoidea), also known as plant lice, greenflies, blackflies, or whiteflies, are common sucker pests, as

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well as ticks (Trombidiformes), thrips (*Thysanoptera*) and true bugs (Hemiptera) (Bondarenko et al. 1991).

Damage disrupts the normal physiology of plants, resulting in decreases in chlorophyll production, changes in activity of respiratory enzymes, decreases in water storage and slower transpiration rates. Overall, the normal life of the infected plant is disrupted, weakening the growth and storage of feeding elements like starch, sugars, oils, etc.

The outlook for an infected plant depends on three *major factors*: (1) specific type of the pests' oral apparatus; that is, sucking or biting; (2) the part of the plant that is damaged: roots, stem, or leaves and (3) whether or not the plant has undergone preliminary preparation by the pest. The combination of these factors results in an extensive range of potential damage and a varied outlook for the plant.

The *most common damage* to plants occurs without any *preliminary preparation* by pests; the pest generally feed on the plant as is. Damage to roots and parts of the plant that are underground could be caused by *such things* as (1) topical bites; (2) deep bites into the root's body; (3) cavities and tunnels inside of the roots and root crops and/or (4) damage inside plant bulbs.

The *stems* and *trunks* of crops might experience damages *such as* (1) drilled channels; for example, holes inside of woody stems and trunks of grassy plants; (2) bite marks and deep bites at the base of stems and trunks and/or (3) distortions and other damage.

Damage to leaves might be (1) rough and random traces of eating, (2) partial eating (i.e. skeletization – the eating of tissues between veins, scrubbing of soft pulp and nibbled edges of leaves), (3) mining (i.e. the formation of mines between layers of epidermis [primary integumentary tissues]), (4) change of colour in sucking spots and (5) leaf contortion as a result of uneven growth of tissues.

The *damage to generative organs* is also variable, *including* (1) inner or surface grazing on vegetative buds; (2) injecting flower buds and fruit; (3) superficial grazing on flowers and their parts; (4) nibbling of healthy open flowers or flower buds from inside; (5) nibbling of plant seeds and ovaries and (6) mining fleshy fruits or tunnelling inside of them, which can cause decay and early fall.

The *economic consequences* caused by pests are variable. In general, the growth rate of plants is decreased due to the damage of photosynthetic leaves. The accumulation of nutrients such as starch, sugar, fats and proteins in seeds, fruits and root crops can also be retarded. This damage leads to a reduction in the mass of green crop output and the weight and quality of seeds, fruits, roots and root crops. *Damage to roots* has similar consequences, resulting in crops that also have a shorter storage life because of the processes of decay. Damage to the *generative organs* leads to decreased productivity and deterioration in taste quality, technical quality, seeding and other qualities.

In general, pests are less harmful if they cause damage to parts of the plant such as the *leaves, fresh sprouts and thin roots,* since they recover more easily. Damage to *stems, trunks, or thick roots,* on the other hand, causes more harm. In these cases, the damage might lead to a complete blockage of the delivery of substances to the whole plant or part thereof. Economically speaking, the *worst consequences* are caused by the damage to reproductive organs, such as *growth, seed, tuber and root crops*. Crops lose their commercial quality, even if the defects are minor (Tansky 1988).

Major factors regarding crop loss due to pests are (1) economic factors, including the state of agriculture, level of agrotechnics, etc.; (2) natural factors such as climate, soil and vegetation (either favourable or unfavourable) and (3) specific biology of a particular pest (Agricultural entomology 1976).

Pest population density is a harmful factor in itself, determining the amount of damage to plants. Pests are considered to be present at dangerous population densities when they decrease the productivity of a crop by 3–5% (Tansky 1988).

Agricultural pests cause great *economic losses*. An estimate of global losses in production is 33% according to D. Heinrich and M. Hergt (2003), while other researchers show up to 40% losses (Pimentel et al. 1999), or US$244 billion (Pimentel et al. 1997). The influences of pests on agriculture are considered in Sects. 5.1.1–5.1.3.

5.1.1 Insects

Insects are the most dangerous pests in agriculture. The numbers of species of plants damaged by a particular insect can be *very different*. A specific species of pest can affect a very small number of plant species. There are also omnivorous insects. However, most insects specialize in certain groups of plants, such as cereals, vegetable crops and fruit trees.

Polyphagous insects feed on plants belonging to different botanical families. Most of them have biting

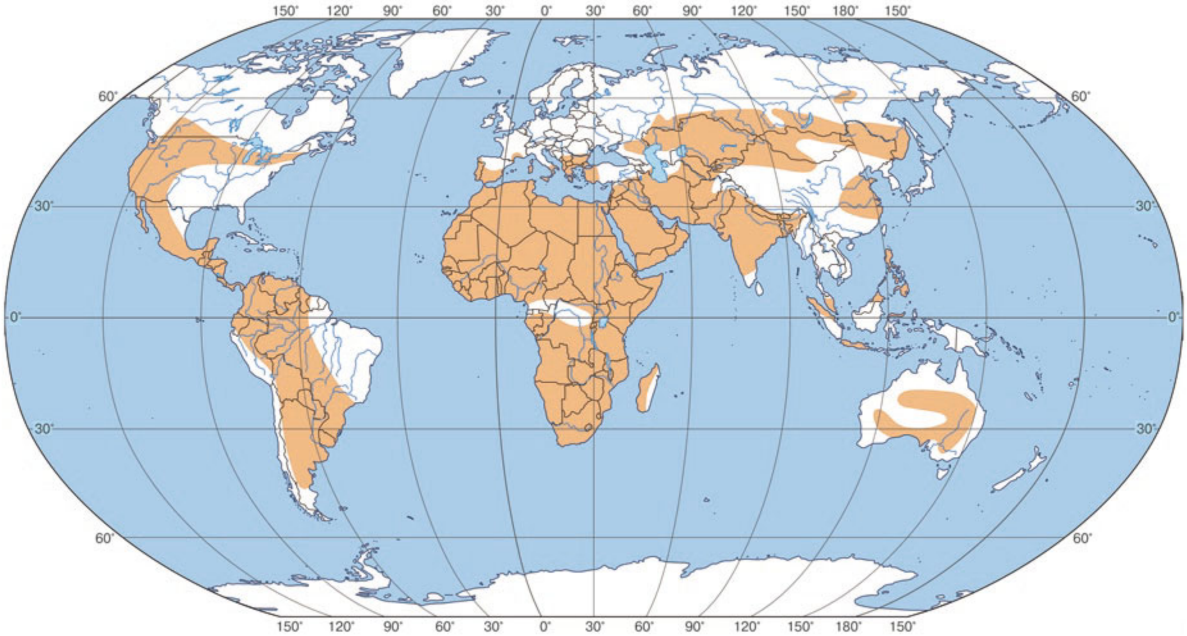

Fig. 5.1 Areas of mass reproduction and invasions of locusts (Adapted from Physico-geographical atlas of the world 1964; http://www.fao.org/docrep/u8480e/U8480E0j.htm)

mouthparts. This group of pests is represented by the order Orthoptera (Acrididae – grasshoppers/locusts; Tettigoniidae–bushcrickets/katydids and Gryllacrididae –leaf-rolling crickets); the order Coleoptera (Curculionidae – weevils/snout beetles/curculinos; Elateridae – click beetles; Scarabaeidae – dung beetles and Tenebrionidae – darkling beetles) and the order Lepidoptera – predominantly the larvae. Multiplying in huge quantities, some highly polyphagous insects damage and even completely destroy agricultural crops (Agricultural entomology 1976).

Among the *most dangerous* polyphagous insects are some species of *locusts* (*Locusta migratoria* L. – migratory locust; *Dociostaurus maroccanus* Thub – Moroccan locust; *Schistocerca gregaria* Forsk – desert locust and *Calliptamus italicus* L. – Italian locust). Places of their mass breeding are near hot deserts on all continents except south-western South America.

The *distribution* of locusts is based on the existence of *three factors*: high humidity, temperatures of 20–40°C and wind. *Humidity* is necessary, since locusts lay their eggs only on wet ground; *temperatures* of 20–40°C are required for the growth of grass, on which the wingless offspring of locusts feed and *wind* is necessary for their flight, since locusts move in the direction of the wind (Smith 1978). Areas of mass reproduction and invasions of locusts are shown in Fig. 5.1.

A swarm of locusts is considered 'tight' if more than 1 m^2 of the Earth's surface has greater than 100 insects (Skorer 1980). The *size of swarms* can be immense. There have been cases when swarms have darkened 250 km^2 of the sky (Mavrischev 2000). In 1889, a giant swarm of locusts flew from the shores of North Africa across the Red Sea to Arabia. The movement of the insects lasted all day; their mass was 44 million tons (Gorshkov 2001).

In the autumn–winter season in 1961–1962, an *anomalous locust invasion* was observed in India, Pakistan and Iran. During this invasion, in north-east Iran, locusts infested more than 500,000 ha. The intensity of the infestation was such that a space measuring 27 by 12 km was uniformly covered with the larvae of locusts, and their concentrations ranged from 200 to 2,000 larvae per square metre (Bondarev 2003).

Rough grazing is a type of damage to vegetation that is characteristic of all species of locusts. The damage caused by locusts can be colossal. In 125 BC, locusts destroyed all the crops of wheat and barley in the Roman provinces of Cyrenaica and Numidia (North Africa). As a result, almost the entire human population there died from hunger – 800,000 people (Mavrischev 2000). In 1962, southern Moroccan locusts wiped out 7,000 ton of oranges, or 60 ton/h in 5 days, which exceeds the annual consumption in a country such as France (Horrors of Nature 1996).

Photo 5.1 Among the most dangerous polyphagous insects are some species of locusts. Rough grazing is the type of damage to vegetation that is characteristic of them. The photo shows a desert locust (*Schistocerca gregaria Forsk*) swarm (about 3–6 km^2) milling over a field of harvested millet north of Bambey, Senegal (Photo credit: M. de Montaigne, 1993. The picture is presented by FAO, image 17139)

Another dangerous polyphagous pest is the *meadow moth* (*Loxostege sticticalis* L). It is a primary pest of sugar beet, and it also causes great damage to cotton plants, sunflower crops, cannabis, lucerne, tobacco, many vegetables, melons and industrial crops (Insects and ticks – crop pests, vol III, Part 2, 1999). *Losses* of tilled and vegetable crops reach up to 40%, and losses of sugar beets reach up to 80% in extreme years. A severe outbreak of the webworm (the larva of this moth) was observed in Russia in 1986–1989. At that time, the area inhabited by its caterpillar larvae covered more than four million hectares (Finnov 1997).

The damage inflicted by *highly specialized pests* is often comparable with that caused by polyphagous pests. One such pest is the *grape phylloxera* (*Viteus vitifolii Fitch*).

This insect came from North America and was introduced into many countries. The grape phylloxera is very harmful to grapevines, sucking juices from the roots and causing their deformation and fracture, and sometimes damaging the leaves (Insects and ticks – crop pests, vol I, 1972).

When this pest reached Europe, it caused tremendous damage to grape growing (local grape varieties were significantly less resistant than North American varieties). For example, in *France*, it provoked a crisis and ruined many vineyards. The *most devastating effects* were recorded in 1884, when phylloxera ruined the vineyards over an area of 1.2 million hectares, which corresponded to economic losses of 7.2 billion francs (Painter 1953).

Currently, there are 128 species of *insect pests* for *wheat* crops, 128 species for *corn*, 73 for *barley*, 70 for *rye*, 42 for *oats*, 41 for *rice* and 24 for *millet*. The *most vulnerable* is the rice crop. The rice crop showed losses of 26% on account of all insect pests, while wheat and rye losses were 5% and 3%, respectively (Bondarenko et al. 1991).

Cereal crops are damaged by *polyphagous insects* (Acrididae – locusts; Tettigoniidae – bush crickets/katydids; Elateridae – click beetles; Noctuidae – owlet moths; *Ostrinia nubilalis* Hbn. – European corn borers; and others) as well as by a number of *specialized pests*.

These include cereal aphids (Aphididae), thrips (Thripidae), Eurygaster (*Eurygaster integriceps* Put), scarab beetles (Scarabaeidae), some owlet moths (Noctuidae), fruit flies (*Oscinella frit* L), weevils/snout beetles/curculios (Curculionidae), European wheat stem sawflies (*Cephus pygmaeus* L), amongst others. During one era, the Great Plains in the United States and Canada were losing up to 80% of the wheat harvest because of the European wheat stem sawfly (Rice 1986).

Grain legumes are damaged most frequently by polyphagous insects such as wireworms (larvae of click beetles); Elateridae; silver Y moths (*Autographa gamma*); cabbage moths (*Mamestra brassicae* L.) and beet webworms (*Loxostege sticticalis* L.). The *most destructive* of the specialized pests are aphids (*Acyrthosiphon pisum Harris*); Sitona weevils (*Sitona* spp.); pea weevils (*Bruchus pisorum* L.); dried bean weevils (*Acanthoscelides obtectus* Say) and pea moths (*Cydia nigricana* F.) (Bondarenko et al. 1991).

Sugar beet roots contain high concentrations of sucrose and, hence, are a great attraction as a food source to many insects, including harmful pests. The world is losing 8.3% of the crop on account of harmful pests yearly (Bondarenko et al. 1991). There are approximately 300 species of insect pests on record that damage sugar beets, including more than 130 species of the beetles, 60 species of butterflies and moths and approximately 40–50 species of aphids, bugs and grasshoppers.

The *most destructive polyphagous pests* are the winter moth, meadow moth and larvae of both click and scarab beetles. The most destructive specialized pests are beet leaf/black-bean leaf aphids (*Aphis fabae* Scop.) and sugar beet root aphids (*Pemphigus populivenae (betue)*); beet bugs (Miridae) and different types of sugar beet weevils (Curculionidae) (Agricultural entomology 1955).

The *cotton crop* is also heavily damaged by harmful insects. There are 1,326 species of such insects on record around the world (Rice 1986). Cotton seeds and seedlings are damaged by wireworms; cutworms (larvae of the turnip moth) and false wireworms (Tenebrionidae). Roots and underground parts of stems are also damaged by wireworms (Elateridae) and mole crickets (Gryllotalpidae). Leaves are damaged by the larvae of the beet borer/armyworm/asparagus fern caterpillar (*Spodoptera exigua* Hbn.); the cotton bollworm/scarce bordered straw (*Helicoverpa armigera* Hbn.); the marbled clover moth (*Heliothis viriplaca* Hufn) and other cutworms, locusts, aphids and thrips. The larvae of the small, thin grey moth, known as the pink bollworm (*Pectinophora gossypiella* Saund.), chew through cotton lint to feed on the seeds. Generative organs of cotton crops are damaged by the cotton bollworm (*H. armigera*) larvae and also by the beet borer/armyworm (*Spodoptera exigua*) (Bondarenko et al. 1991).

In the past, the most destructive worldwide pest to the cotton crop has been the pink bollworm (*Pectinophora gossypiella*). In Egypt, losses were 30–40% of its cotton; Brazil, 30–60% (Insects, vol III, Part 2 1999) and Mexico, 20–25% (Agricultural entomology 1976).

Since 2000, however, yield *losses have fallen sharply*. Cotton losses to arthropod pests reduced overall yields by 2.58%. Thrips took top ranking at 0.713% loss. *Lygus* were ranked second at 0.614%. The bollworm/budworm complex (0.486%) ranked third, stink bugs were fourth at 0.371% and fall armyworms were fifth at 0.113%. Total cost and loss for insects in 2009 was $502 million. Direct management costs for arthropods were US $43.33 per acre (http://www.entomology.msstate.edu/resources/tips/cottonlosses/data/2009/2009loss.php).

Annual losses of *potato crops* due to pests amount to 6.5% (Agricultural entomology 1976). Potatoes are damaged mainly by polyphagous insects. The *most dangerous pest* of potatoes is the *Colorado potato beetle/Colorado beetle/ten-striped spearman/potato bug* (*Leptinotarsa decemlineata* Say.). Between 20 and 40 beetles can destroy half a potato bush, which leads to a reduction in yield by a factor of 2–3 (33–50%). If pests eat all of the leaves on the bush, the potato yield is reduced by a factor of 10 (Bondarenko et al. 1991).

Total *economic losses* from pests are historically very high. In pre-revolution Russia, the total damage caused by them amounted to 980 million gold rubles (corresponds to modern US$29.4 billion). The

Photo 5.2 The cotton crop is heavily damaged by harmful insects. Among the most harmful plant pests is the cotton bollworm, which inflicts damage to leaves and fruits. The photo shows larva(e) of a bollworm (*Helicoverpa zea*) attacking a boll (Photo credit: Clemson University, USDA Cooperative Extension Slide Series, Bugwood.org)

Photo 5.3 The most dangerous pest of potatoes is the Colorado potato beetle (*Leptinotarsa decemlineata Say*). If the insects eat all of the leaves on the bush, the potato yield is reduced by ten times. Damage to potato foliage by larvae of the Colorado potato beetle is shown (Photo credit: USDA APHIS PPQ Archive, USDA APHIS PPQ, Bugwood.org)

amounts lost were 10% of its gross production; horticulture, 20% and gardening, 40% (Agricultural entomology 1955). During the period 1983–1990, the world was spending US$210 billion each year to combat agricultural and forest pests (Akimova and Khaskin 1999).

The influences of insect pests on human activities are illustrated by Photos 5.1–5.3.

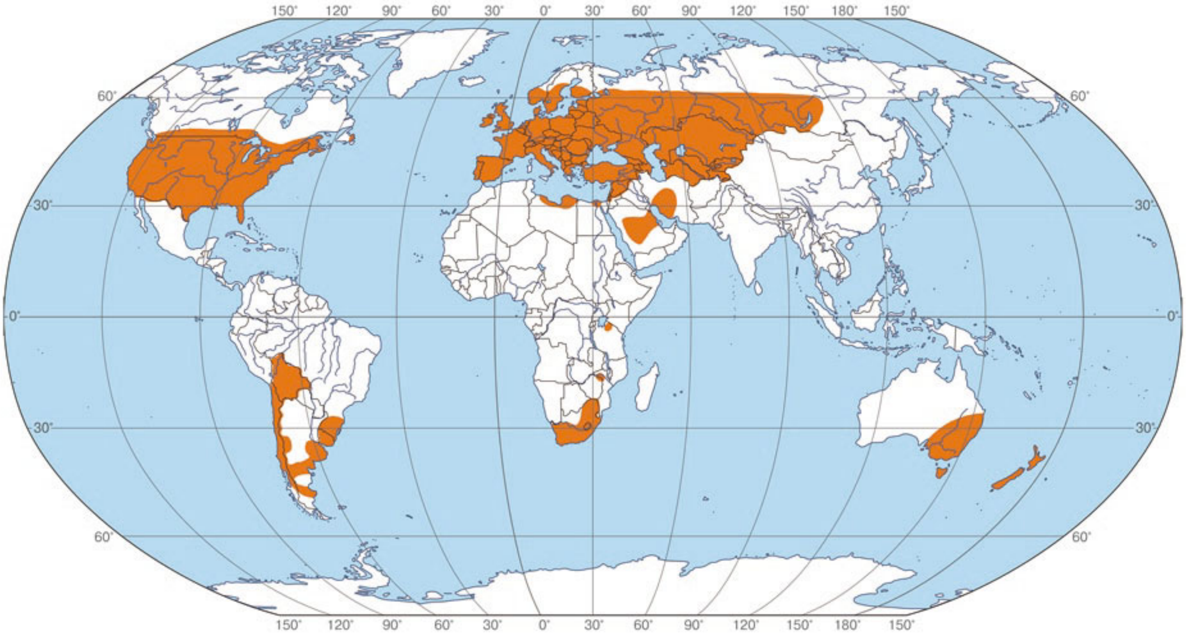

Fig. 5.2 Global distribution of the Pear Leaf Blister Mite (*Eriophyes pyri* Pgst.) (Adapted from CABI Distribution Maps of Plant pests. Map No. 273 (Copyright CAB International. Wallingford, UK; www.cababstractsplus.org/dmpp. The map partly based on the Agroecological atlas of Russia. http://www.agroatlas.ru/ru/content/pests/Eriophyes_pyri/map/. Reproduced with permission of CAB International)

5.1.2 Mites, Nematodes and Molluscs

Animals in this section belong to a variety of taxa. *Mites* belong to the class of arachnids (Arachnida) and *nematodes* belong to phylum Nematoda, while *molluscs* constitute a different type of invertebrate animal (phylum Mollusca).

A distinctive *feature* of phytophagous *mites* is the minute, sometimes microscopic, size of the body. Damage to plants is produced mainly during feeding. Most mites are polyphagous; that is, they are able to feed on plants of different families.

There are good examples of polyphagia, such as the red spider mite/two-spotted mite (*Tetranychus urticae* Koch.); garden spider mite (*Schizotetranychus pruni Oud*.); European red fruit mite/fruit tree red mite (*Panonychus ulmi* Koch.); flat scarlet mite (*Cenopalpus pulcher* Can. et Fanz.); strawberry spider mite (*Tarsonemus turkestani*); amongst others. These mites can feed on and cause damage to approximately 600 different species of plants (Handbook of agronomist on plant protection 1990).

Most mites cause harm to (1) field and vegetable crops and (2) fruit trees and berry bushes. The common spider mite is the most harmful pest to field and vegetable crops. Normally, it damages cotton, soybeans, beans, potatoes, hops and various melons. In some years, yield losses of cotton reached 25–30% in Tajikistan and 20–60% in Uzbekistan (Bondarenko et al. 1991).

Mites cause *considerable damage* to fruit trees and berry bushes. For example, the pearleaf blister mite (*Eriophyes pyri* Pgst.) often leads to losses of up to 90% of a pear crop, while the strawberry mite reduces the yield of berries by 40–70%. The brown fruit mite (*Bryobia redikorzevi* Reck.) and hawthorn spider mite (*Tetranychus viennensis* Zach.) sometimes diminish the apple crop by 65% in the United States (Bondarenko et al. 1993). The global distribution of pearleaf blister mite (*Eriophyes pyri Pgst.*) is shown in Fig. 5.2.

There are approximately 4,000 phytophagous species of *nematodes* out of 28,000 described that exist worldwide. Phytonematodes are almost microscopic because vast numbers of their species have body lengths of only 0.5–1.5 mm. Some of them are even smaller (0.1 mm), while others are up to 12 mm.

The *extent of destruction* by nematodes depends on the following *factors*: (1) concentration of the infestation;

Photo 5.4 The tongues of molluscs are covered with a great many small, sharp teeth with which they saw off small pieces of plants and swallow them. The photo shows a great grey slug (*Limax maximus*) on a tomato slice. This species is listed as a major agricultural pest in the United States. The photo was taken on 14 September 2010 in Maryland (United States) (Photo credit: http://en.wikipedia.org/wiki/File:Maryland_Leopard_Slug.jpg)

(2) species of plants; (3) agricultural technology; (4) state of plants' physiology; (5) type of soil; (6) weather conditions and (7) the presence of natural enemies. The impacts of nematodes on plants may involve mechanical, physiological and/or biochemical damage.

Most nematodes are polyphagous species, with the grass root-gall nematode (*Subanguina radicicola* Greef.*)* being observed on more than 1,500 species of plants. This species is very harmful to tobacco plants, sugar beets, cucumbers, tomatoes, melons, cabbage, many essential oil cultures, alfalfa and clover (Bondarenko et al. 1991).

The *impacts* of *nematodes* on crops can be (1) direct loss of crops; (2) reduced quality of products; (3) restriction of agricultural production and (4) the transfer of plant pathogens. World crop production *losses due to nematodes* averaged 12% (Bondarenko et al. 1993). There are up to 7.5 billion nematodes per hectare of land, most of which live in the top 7–8 cm of soil. Nematodes can cause histological damage to plant roots, bulbs, stems, leaves, flowers, fruits and seeds (Rice 1986).

Nematodes affect virtually all crops in all sectors of agriculture. The *cereal cyst/Ustinov cyst nematode* (*Heterodera avenae* Wrr.) is the most harmful pest of cereals and grain legumes. It inflicts the maximum damage to wheat, barley and oats, but it also damages rye, corn, millet, sorghum and many grasses (bluegrass, fescue, rump, timothy, etc.). Infestation of a crop with cereal nematodes leads to slower plant development, growth inhibition, formation of immature spikes and a decrease in yield. For example, losses of wheat and oat crops in the Volga region (Russia) have been as high as 60% (Bondarenko et al. 1993).

Nematodes cause considerable damage to *potato* crops; for example, 150,000 ton of potatoes were lost in 1 year due to the potato tuber nematode (*Ditylenchys destructor* Thorne) in the Carpathians of Ukraine, during the period 1961–1964 (Kiryanova and Krall 1971).

The main pest of sugar beet is the *sugar beet nematode/cyst eelworm* (*Heterodera schachtii* Schmidt). Infested plants are stunted as the nematode causes potassium and phosphate starvation. This leads to a dramatic reduction in sugar content and reduces root mass. For example, the damage due to this nematode on sugar beet fields in Mecklenburg County in Germany was so great that it almost eliminated the beet crop. This led to the closure of several sugar factories (Bondarenko et al. 1993).

Nematodes are one of the world's major agricultural pests, causing an estimated US$80 billion in *worldwide crop damage* annually (http://www.divergence.com/ma_crop_protection.php).

Terrestrial molluscs harmful to agriculture belong to three *families*: (1) keelback slugs (Limacidae); (2) roundback slugs (Arionidae) and (3) typical snails/land snails (Helicidae). These molluscs live among grasses and in soil interstices, moving slowly with their muscular foot. Their tongues/radulae are covered with numerous small, sharp teeth, which they use to tear small pieces of plants and swallow them.

Photo 5.5 The effects of phytonematodes are in the mechanical and physiological-biochemical damage to plants. They can also do damage to roots, bulbs, stems, leaves, blooms, fruits and seeds of several tens to 1,500 species of plants. The photo shows *Trichodorus primitivus* damage to sugar beets; a plant from a treated plot is on the right (Photo credit: A. Steele, http://www.nematologists.org/)

Photo 5.6 One hectare of land can contain about 7.5 billion nematodes, most of which fall into the upper 7- to 8-centimetre soil layer. The photo shows 'hotspot' in peanut field infested with *Meloidogyne hapla.* The light fragment is a section affected by nematodes (Photo credit: R. A. Motsinger, http://www.nematologists.org/)

Plants damaged by slugs include cereals, vegetables, flowers, technical crops, citrus fruits and grapes. Slugs cause great damage to agriculture in northern and north-western Europe, the United States, Canada and southern Australia. For example, the losses of potato crops and winter wheat were estimated in England and Wales in 1967 at 645,700 and 191,700 lb sterling, respectively. It is believed that slugs also destroyed 36,000 ton of potatoes each year in these regions of the United Kingdom (Likharev and Viktor 1980).

All terrestrial slugs are polyphagous. The *most susceptible* plants include seedlings of cucumbers, tomatoes and cabbages. Sometimes slugs consume 80–100% of seedlings (Likharev and Izzatulayeva 1983). Crops such as winter rye, winter wheat, various legumes, cruciferous vegetables and carrots suffer from severe damage.

The most common and widespread species are the grey field slug (*Agriolimax agresti*s L.) and the brown-banded arion (*Arion circumscriptus* Jhn.), causing damage to winter cereals, vegetables, potatoes and other crops.

The *edible snail/Burgundy snail/Roman snail* (*Helix pomatia* L.) is a major pest of the tree-snail family; it consumes buds and leaves on the vine, and flowers and leaves of apricot, peach, and other fruit trees.

The effects of mites, nematodes, and molluscs on various branches of growing plants are illustrated in the Photos 5.4–5.6.

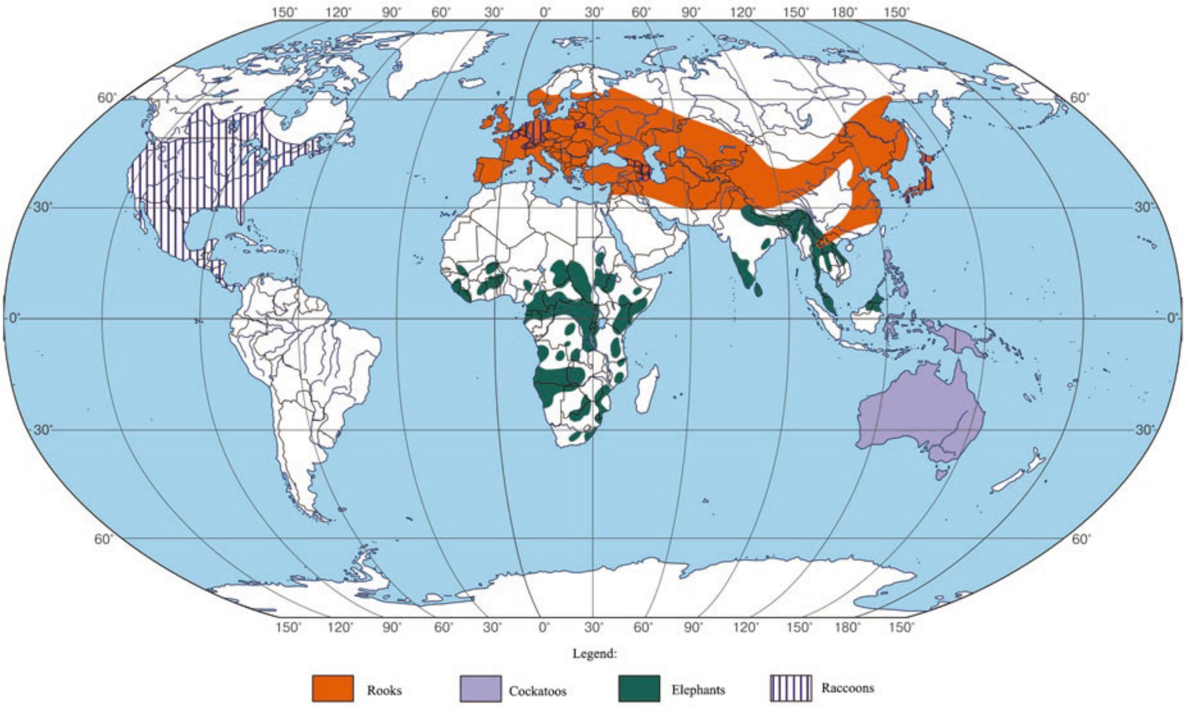

Fig. 5.3 Global distribution of some mammals and birds – agricultural pests (Adapted from http://commons.wikimedia.org/wiki/File:Raccoon-range.png; http://en.wikipedia.org/wiki/Cockatoo; http://commons.wikimedia.org/wiki/Corvus_frugilegus; http://www.waza.org/en/zoo/visit-the-zoo/elephants-1254385523/loxodonta-africana; http://www.waza.org/en/zoo/visit-the-zoo/elephants-1254385523/elephas-maximus)

5.1.3 Mammals and Birds

Among *mammals*, the maximum damage to crops is brought about by *rodents*, which are predominantly herbivorous animals that feed on the green parts of plants, seeds and the bark of trees. The *most harmful rodents* known are marmots, ground squirrels, rats, mice, hamsters, rabbits, jerboa and others. The global distributions of some mammals and birds considered to be agricultural pests are shown in Fig. 5.3.

Damage caused by rodents is primarily due to their *foraging activities*. They affect mainly crops such as grains, vegetables and fruits.

The damage to *grain crops* is associated with activities such as digging up sown grain, eating sprouts, biting stalks and cutting and biting off ears. When mass breeding of rodents occurs, consequences can be catastrophic. For example, the common vole (*Microtus arvalis* Pall.) destroyed 80% of rye and wheat crops in 1914 in Ukraine. They damaged 22.3–68.7% of fall wheat, 19.1–71.6% of fall rye, and 8.5–15.0% of fall barley crops in Czechoslovakia in 1950 (Bondarenko et al. 1993).

The damage caused by rodents to *vegetable* and *melon crops* is in general, less distinctive. The wood mouse/long-tailed field mouse (*Apodemus sylvaticus* L.) gnaws the flesh and eats away seeds of melons, cucumbers, and tomatoes. The striped field mouse (*Apodemus agrarius* Pall.) is seriously harmful to roots and also squash vegetables, while pocket/true gophers (Geomyidae) affect all kinds of melons. Jerboa (Dipodidae) dig up and eat the germinating seeds of melons, cucumbers, and sunflower seeds. Living permanently underground, mole rats (Spalacidae and/or Bathyergidae) mostly spoil roots (Sokolov 2008).

Rodents significantly damage *fruit crops*. They eat the seeds and fruits, dig germinated seeds from soil, gnaw bark, and weaken twigs. For example, each fat/edible dormouse (*Glis glis* L.) ate 400 pears in the North Caucasus during summertime (Biology of woodland choir and beasts 1975).

The list of damaged crops is not limited to those just mentioned. The *red-tailed gerbil* (*Meriones erythrourus*) causes significant damage to *cotton*, gnawing bolls and removing seed husks. Field and forest mice, and gophers actively damage the *sunflower* crop. Rodents also lead to losses of *potato* crops, which serve as food to field mice; European/black-bellied/common hamsters (*Cricetus cricetus* L.) and Transbaykal zokors (*Myospalax psilurus* Ml-Ed.) (Sokolov 2008).

Rodents cause serious damage to *pastures*. When population densities reach 30 gophers per hectare, they can reduce the annual crop of green forage (dry weight) by more than 1,125 kg/ha, which is 38% of the total crop. Voles can destroy up to 4% of the annual harvest of alfalfa if their population density is 250 per hectare. Gopher rodents destroy a quarter to a third of the crop of alfalfa in North and Central America (Rice 1986).

Rodents are considered *significant agricultural pests*. By some estimates, rats kill and damage up to 25% of crops in India (Bondarenko et al. 1993).

In the case of large mammals, significant damage occurs to crops just by animals *passing through farmland*. The list of large crop-damaging mammals varies greatly worldwide. In the United States, the most problematic species are deer (*Odocoileus* spp.); raccoons (*Procyon lotor* L.) and coyotes/American jackal/prairie wolf (*Canis latrans* Say) (Conover 1998).

In *southern China* (Yunnan province), the main pests of crops are elephants, monkeys, bears, gaur (includes bison, domestic cattle, yak and water buffalo), deer and wild pigs. The Indian/Asian/Asiatic elephant (*Elephas maximus* L.) causes approximately 90% of crop loss (Tisdell and Xiang 1995). In the *temperate forest zone*, problematic species includes some ungulates, wild boar and bears. For example, bears are detrimental to oat plantations. In remote districts of the Leningrad and Vologda regions of Russia, two to three bears can sometimes tear and trample 10–15 ha of autumn crops (Pazhetnov 1990).

Estimates of *economic damage* caused by wild mammals are scarce. In the United States in 1992, surveyed farmers spent an average of 43.6 h and US$1,002 trying to stop or prevent crop damage by wildlife (Conover 1998). In 1989 alone, wild animals damaged crops in the whole country at a cost estimated at US$343 million (Conover et al. 1995). Agricultural damage from wild animals was four million yuan, or about US$482,000, in the Xishuangbanna county of Yunnan province (China) in 1994 (Tisdell and Xiang 1995).

The *most important* large agricultural pests are *Indian elephants*. They consume crops such as rice, corn, bananas and capsicum. Much of the damage they cause results from trampling (Tisdell and Xiang 1995). Very large losses from wild elephants occur in Sri Lanka. Yearly, they account for losses of 1,121 billion rupees, or about US$12 million. In the southern part of the country, the average value of crop losses is 12,049 rupees (US$128) per farmer, which is more than a third of their earnings (Bandara and Tisdell 2003).

Birds are also recognized as significant pests. The *main damage* is caused by their *feeding activities*. Herbivorous and omnivorous species of birds damage the following *branches* of agriculture: (1) grain growing; (2) fruit growing; (3) vegetable growing and (4) the seed production and breeding of new plants.

The destructiveness of some species of birds may be extremely high. For example, in Scotland, *rooks* eat up to 25% of sown oats and 20% of barley. In the United States, the loss of grain to passerine *red-winged blackbirds* (*Agelaius phoeniceus* L.) is an average of 16.2% of the crop (Ilyichev 1984).

Significant damage is caused by other birds, mainly the *rosy starling (Sturnus roseus L.)* and *European/common starlings (Sturnus vulgaris L.)*. They affect up to a third of the vineyard crop in southern Europe and North Africa (Naumov and Ilyichev 1965). These species also damage stone fruits such as cherries, plums and apricots in the southern parts of the former Soviet Union.

In the northern Italian province of Ferrara, the *pheasant* (Phasianidae) is the most significantly destructive bird. Pheasants destroy vegetables and other crops. *Starlings (Sturnidae)* and *sparrows* (Passeridae) cause significant damage to fruits and grapes. *Magpies* (Corvidae) damage melons by biting and poking them. *Wild pigeons* (Columbidae) and *ducks* (Anatidae) spoil coarse cereals (Pagnoni 1997).

The influence of mammals and birds on various sectors of plant growth is illustrated by Photos 5.7–5.9.

Photo 5.7 In a number of regions, animals are among the dangerous agricultural pests. For example, the most important agricultural pests in the countries of Southeast Asia are Indian elephants. They consume such crops as rice, corn, bananas and capsicum. Much of the damage they cause results from trampling. The photo shows electric fences at Yala Park, Sri Lanka, which are built to keep wild elephants from invading land cultivated by farmers (Photo credit: G. Bizzarri, 1993. The picture is presented by FAO, image 17044)

Photo 5.8 Bird damage is a significant problem in Australia, with total damage to horticultural production estimated at nearly $300 million annually. Over 60 bird species are known to damage horticultural crops. The photo shows a juvenile starling feeding on a pear in Orange, New South Wales (Photo credit: B. Lukins (NSW Industry & Investment, Australia), 30 January 2004)

Photo 5.9 One of the most ancient and widespread methods of protecting crops against birds is duds. A dud in southern Primorsky Krai (Russia) is shown (Photo credit: Yu.S. Govorushko, 3 May 2008)

5.2 Forest Pests

This section includes *animals* that *damage* or *destroy trees*. *Insects* are the most important in terms of damage. Mammals (primarily rodents), birds, mites and nematodes are also of some importance. The spread of forest pests is simple: they are present wherever there is a forest.

In every forest, there are a number of pests. Some of them are widespread and cause considerable damage, and others have less effect. Certain species cause continuous harm, while others cause occasional harm; for example, in times of mass reproduction. Some pests cause significant damage where poor forest management exists.

Major groups of forest pests are discussed below.

5.2.1 Insects

Insects are the most economically important forest pests. The vast portion of damage to trees occurs during the process of *insect feeding*. Insects cause damage by biting off and eating parts of trees and shrubs, mostly pine needles, leaves, bark and roots. They eat the seeds, damage the leaves, suck tree sap, build tunnels under the bark, burrow into the wood and form excrescence and other substances that stress trees and shrubs. These injuries in turn cause a variety of effects: distortion of stems, dying and/or felling of branches, stunting of shoots and leaves and reduced flowering, fruiting and growth. Where severe damage occurs, plants often die (Polyakov and Nabatov 1992).

Forest pests are divided into the following *groups*, based on the range of host tree species: *polyphagous* (feed on many different kinds of plants), *oligophagous* (feed on a limited number of plants) and *monophagous* (feed on one specific plant family).

Polyphagous pests include the gypsy moth (*Lymantria dispar* L.), pale tussock moth (*Calliteara pudibunda* L.), winter moth (*Operophtera brumata* L.), mottled umber (*Erannis defoliaria* Cl.), cockchafer/may bug/billywitch/spang beetle (*Melolontha hippocastani* F.) and others.

An example of an *oligophagous* pest is the black arches, or nun moth (*Ocneria monacha* L.), which causes damage mostly to conifers, except juniper and yew, and some hardwoods.

Monophagous pests include the pine beauty moth (*Panolis flammea* Schiff.), bordered white/pine looper moth (*Bupalus piniarius* L.), the birch bark beetle

Photo 5.10 In the course of development, the insects deposit the eggs from which larvae (beetles) and worms (butterflies) differing greatly from their parents appear. Of them, a great edacity is characteristic; therefore, maximum damage is done to plants just at this phase. Different stages of development and damage inflicted by the poplar borer (*Saperda calcarata Say*, 1824) are presented (Photo credit: James Solomon, USDA Forest Service, Bugwood.org)

(*Scolytus ratzeburgi* Jans.) and others (Zhokhov 1975; Handbook of forester 1980; Protection of forest against pests and diseases 1988).

Insect pests can be divided into the following *categories*: (1) pests of cones and seeds, (2) pests of buds and shoots, (3) foliage pests, (4) stem pests and (5) root pests.

The impacts of insect pests on *cones* and *seeds* are very diverse. The pine-cone moth (*Dioryctria abietella* Den. et Schiff.) and the tortrix moth (Tortricoidea/Olethreutidae) larvae penetrate cones and destroy the bulk of the seeds. Leaf-footed bugs (Coreidae) pierce cones with their proboscis and suck the juice of seeds. Many beetles burrow into young cones, preventing seed development, and the cones consequently become infertile (Berryman 1990). Beetles are not characterized by outbreaks of mass reproduction, as is the case with many other insects (Vorontsov 1982). One of the most serious pests in this category is the larch fly (*Chortophila laricicola* Karl). One larva can kill 40–80% of larch cone seeds and 35–40% of fir cone seeds (Protection of forest against pests and diseases 1988).

Campions (*Silene*) are the most dangerous pests of *buds* and *sprouts*. Larvae of campions mine shoots, causing shrinkage of their buds. Caterpillars of pine-shoot moths (*Rhyacionia buoliana* Den & Schiff.) often damage the main apical stem, which leads to uneven growth of the trunk or multiple branching, which in turn leads to the beginning of secondary apical shoot domination. Due to the pests' attacks, these trees form ugly forked trunks, so their value for commercial timber harvesting is greatly

Photo 5.11 The impacts of insect pests on cones and seeds are very diverse. Many beetles burrow into young cones, preventing seed development, and the cones then become infertile. The photo shows damage to a cone caused by the white pine cone beetle (*Conophthorus coniperda*) (Photo credit: Robert L. Anderson, USDA Forest Service, Bugwood.org)

Photo 5.12 Fir needle- and leaf-eating insects destroy photosynthetic tissues of trees, resulting in a reduction of the formation of carbohydrates. The picture shows tree mortality at La Grande, Oregon (United States) due to the Douglas fir tussock moth, *Orgyia pseudotsugata* (McDunnough) (Photo credit: David McComb, USDA Forest Service, Bugwood.org)

reduced or completely lost. Two of the most destructive insects of this group are the wintering pine-shoot moth (*R. buoliana* Den & Schiff.) and the white pine weevil/engelmann spruce (*Pissodes strobi* Peck.) (Berryman 1990).

Fir needle and *leaf-eating insects* destroy photosynthetic tissues of trees, resulting in a reduction of the formation of carbohydrates. The immediate effect of defoliation is a reduction in tree growth. A study of defoliation of a quaking/trembling aspen (*Populus tremuloides*) by cocoon eaters, in Minnesota (United States), showed that in the course of 1 year, when the crown of the tree was being eaten, tree growth decreased by almost 90%, and the following year, it decreased by 15% (Riklefs 1979).

The *Siberian coniferous silk moth* (*Dendrolimus sibiricus* Tsch.) is among the most hazardous pests of coniferous vegetation. Outbreaks of its propagation often lead to *huge losses*. For example, in 1955, in the central districts of Krasnoyarsk krai, Russia, the total area of infestation was one million hectares (Novikov 1999). The forest lost 140,000 ha, and damaged timber was approximately 50 million cubic metres (Bondarev and Soldatov 1999). During the outbreaks of the *spruce budworm* (*Choristoneura fumiferana*) in the mid-1990s in Alaska (Eaten alive 1998) and the *Douglas fir tussock* moth (*Orgyia pseudotsugata* Lym.) in Oregon and Washington (United States), there were large financial losses (Berryman 1990).

The *gypsy moth* (*Lymantria dispar* L.) should be recognized as the most destructive leaf pest. According to various sources, gypsy moth caterpillars eat leaves from 300 (Liebhold et al. 1997) to 600 (Kuznetsov 1997) different plant species. Among the favourite trees in the Old World are the oak, fruit trees, poplar, willow and birch (Protection of forest against pests and diseases 1988). In North America, oaks and aspen are the best-known hosts (Liebhold et al. 1997). The global distribution of the gypsy moth is shown in Fig. 5.4.

Major damage is caused by its larvae, each of which can eat from 0.6 to 3.5 g of leaves during its development; besides that, approximately one-third of those leaves fall to the ground as leftovers (Protection of forest against pests and diseases 1988). There can be several hundred caterpillars on every tree during their time of mass reproduction.

Outbreaks of the gypsy moth (*Lymantria dispar* L.) can lead to extremely serious consequences; the larch

Fig. 5.4 Distribution of the gipsy moth (www.fs.fed.us/ne/morgantown/4557/gmonth/world. Reproduced with permission of U.S. Department of Agriculture Forest Service)

forests suffer the most in the eastern United States. In 1981, trees were totally devoid of leaves in an area of 12.9 million acres (Liebhold et al. 1997); that is, approximately 5.2 million hectares.

Tree trunk pests include insects from the long-horned beetle family (Cerambycidae), jewel/metallic wood-boring beetles (Buprestidae), true weevils/snout beetles/curculios (*Curculionidae*), horntails/wood wasps (Siricidae), cossid/carpenter moths (Cossidae), clearwing moths (Sesiidae), amongst others. These insects live hidden under the bark or in the flesh of the trunk. They gnaw in the surface layers of the tree trunk (bast/skin fibres, cambium, sapwood), causing substantial physiological damage to the tree and their ultimate demise (Protection of forest against pests and diseases 1988). Most trunk pests are oligophagous and are found in several species of trees (Concomitant of forester 1990).

Quite a lot of destructive trunk pests belong to the subfamily of *bark beetles* (Scolytinae), numbering more than 3,000 species. The peculiarity of this family is that not only the larvae but also the adult beetles live under the bark and in the wood flesh of tree trunks. They make complex mines relatively constant in form for each species. Bark beetles can damage the majority of forest tree species, mainly conifers (Biological encyclopaedic dictionary 1986).

Bark beetles typically undergo outbreaks. For example, a mass outbreak of a specific bark beetle – the spruce beetle (*Dendroctorus rufipennis* Kirby) – was observed in Alaska in the mid-1990s. There were 1.3 million hectares of Sitka-Canada spruce hybrids destroyed as a result (Eaten Alive 1998). They also damage approximately two million cubic metres of timber spruce each year in the United States alone (Holsten et al. 1985).

Root pests includes insects living in the upper soil, such as chafers, root eaters and other scarab beetles, click beetles, darkling beetles, farina eaters and other insects (Zhokhov 1975). In general, these pests do not pose a great danger for the development of trees with well-developed root systems, though they may contribute to fungal infections that cause root rot. The main problems are caused in nurseries and young plantations, as saplings and seedlings are small and have tender roots. The pests violate the normal growth of young plants by gnawing and biting them and, in some cases, cause their death (Berryman 1990).

Forest insect pests affect the following *types* of human activity: (1) forest industry; (2) agroforestry and reforestation; (3) recreational activities and (4) hunting.

Typical *consequences* for the *first two* human activities include (1) loss of mature trees; (2) death of young plants, seedlings and seeds; (3) reduction of tree diameter and height and (4) deformation of trunks.

The *loss of mature trees* has the most important and economically significant effects. The degree of decline in the quality of wood of dead trees depends on several factors: breed, size of trunk, causes of death, prevailing environmental conditions, etc. For example, hemlock (Pinaceae, Genus *Tsuga*), wood, and balsam fir (*Abies balsamea* L.) often lose their commercial quality within 3 years, while other species may remain suitable for timber sales for decades (Berryman 1990).

The *loss of seeds* and *seedlings* causes extensive damage in developing forest plantations or natural regeneration. *Reduced height* of seedlings weakens their competitiveness compared with other trees and can consequently result in colonization by undesirable species. Decreases in diameter gain have major impacts on the output of timber. *Deformation of trees* (bending and splitting of tree trunks) leads to decreases in the value and yield of commercial timber. Such trees provide shorter logs in assortments, and costs of harvesting and timber processing often increase.

Impacts on *recreational activities* occur due to a decrease in the aesthetic merits of planted forests and the overall deterioration of recreational areas. *Hunting activities* can be influenced due to deterioration in the living conditions of game animals. The destruction of crop seeds and nuts decreases the populations of a number of game species (Zhokhov 1975).

The *economic importance* of insects as pests of forests is significant. They are a major factor in the death of forests. In 1995, 172,000 ha of forests in Russia were totally lost, 46% as a direct result of insect pests (Nikanorov and Khoruzhaya 1999). Each year in Canada, approximately 850,000 m^3 of timber are spoilt due to diseases and pests (primarily insects) in an area of 32 million hectares (Sokolov 2008).

The impacts of insects on forest tree species are illustrated by Photos 5.10–5.12.

5.2.2 Nematodes and Mites

Nematodes are extremely capable of inhabiting varied and extreme ecosystems. Many species are soil inhabitants, and as such, they primarily damage roots. However, they are often carried by insects to other parts of plants and penetrate into wood. There are quite a large number of species of nematodes that damage trees and shrubs. For example, representatives of up to 20 genera of nematodes eat only fir seedlings.

Nematodes can be divided according to the species of plants they affect, that is, polyphagous, oligophagous, and monophagous groups. Examples of *polyphagous nematodes* include the American dagger nematode (*Xiphinema americanum*), which causes damage to approximately 70 species of trees and shrubs; the lesion nematode (*Pratylenchus penetrans*), which feeds on 50 different kinds of plants and others.

Oligophagous nematodes include the willow cyst nematode (*Heterodera salixophia*), which affects ten species of willows. *Monophagous nematodes* are mono feeders; for example, *Criconema seymouri* is specific to the coniferous western red cedar tree (*Thuja plicata* D. Don) in Canada, and *Xiphinema arcum* parasitizes only the Himalayan/Deodar cedar (*Cedrus deodara* (Roxb.) G. Don) in India (Kiryanova and Krall 1971).

Nematodes penetrate into wood, damage plant cells, and suck their liquid content. *Such effects* are produced by the: (1) oesophageal gland secretions which adversely affect the plant, and (2) the creation of suitable conditions for the entrance of infection through damaged sections. For example, one individual nematode, *Tylenchys emarginatus*, can cause more than 500 small lesions to root cells of spruce seedlings in 1 day, which in turn creates gateways for the infiltration of pathogenic fungi (Kiryanova and Krall 1971).

The impacts of nematodes on trees depend on many *factors*, such as the following: (1) the susceptibility of a particular tree species; (2) the concentration of nematodes in the soil and (3) the percentage of individuals of this species compared to the number of all other nematodes that live near the roots in the soil.

One of the most destructive nematodes is the *pine wood/wilt nematode* (PWN) (*Bursaphelenchus xylophilus*), which affects many species of conifers. In 1913 in Japan, withering pines were first noted. In the 1930s, this phenomenon was named 'pine wilt' and was observed in 12 prefectures of the country. By the

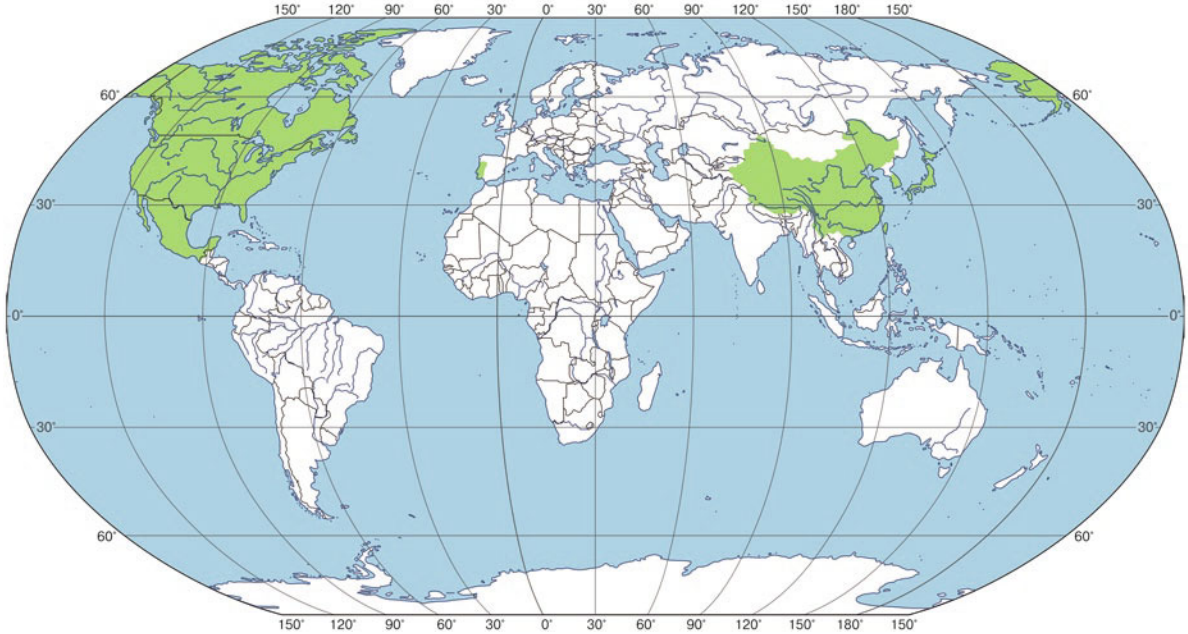

Fig. 5.5 Countries in which the pine wood nematode was found (*Bursaphelenchus xylophilus*). Compiled by author

1940s, it was noted in 34 prefectures. However, the cause of decay and death of trees was only established in 1969. Currently, the pine wood nematode has affected a total forest area of 650,000 ha, which corresponds to a quarter of all forests in Japan (Kulinich and Kozareva 2004). Countries in which the pine wood nematode has been found are shown in Fig. 5.5.

The impact of this nematode on trees is due to *three factors*: (1) cavitation, or clogging up of conducting vessels by air plugs; (2) toxins excreted by the nematode and (3) metabolites that come from infected areas of tissue. The consequences of the *symptoms* are as follows: (1) the discontinuation of the formation of gum, (2) decrease and consequently complete cessation of transpiration, (3) wilting and browning of needles and (4) total loss of the tree (Kulinich and Kozareva 2004).

Nematodes are *transferred* from dead trees to living stems by other pests, such as long-horned beetles (Cerambycidae), which themselves reproduce in the withering tree. After the flight to an uninfected pine, nematodes leave the carrier insect and penetrate into the resin through the lesions caused by insects. Total *damage* caused by these pests to coniferous species is significant. In Japan, the annual loss of timber amounted to 2.4 million cubic metres in 1970. In China, pine wood nematodes killed 35 million pine trees between 1982 and 2000 (Xu 2003).

Other important pest species include the *boxwood spiral nematode* (*Rotylenchus buxophilus*). It is common in the United States, India, Spain, France, Austria and Poland. It damages the common/European boxwood (*Buxus sempervirens* L.), the Himalayan cedar (*Cedrus deodara* (Roxb.) G. Don), the Mediterranean cypress (*Cupressus sempervirens* L.) and several other tree species.

There is also the lance nematode (*Hoplolaimus galeatus*) in Canada and 14 states of the United States, which is a parasite of over 50 species of coniferous and deciduous trees, including birch, elm, oak, cedar, Douglas fir, other species of fir, larch, sycamore, yew, hemlock, Thuja and 9 species of pine (Kiryanova and Krall 1971), amongst others.

The number of species of *mites* that injure forest trees and shrubs is small. They are pests of fruit crops basically and damage wild species only on a 'part-time' basis. Among the *most significant* 'part-timers' for forestry is the European red mite (*Panonychys ulmi* Koch.). This mite damages elm, alder, oak, sycamore and other trees. The garden spider mite (*Schizotetranychus pruni* Oud.) can feed

Photo 5.13 One of the most destructive nematodes is the pine wood nematode (*Bursaphelenchus xylophilus*), which affects many species of conifers. The photo shows a pine wood nematode moving from the axial resin canal to the radial resin canal of a diseased pine tree (radial face of wood) (Photo credit: Y. Mamiya, Tamagawa University, Japan)

Photo 5.14 Japan suffers to the maximum extent from the pine wood nematode. Currently, the pine wood nematode has affected a total forest area of 650,000 ha, which corresponds to a quarter of all forests in Japan. The photo shows severe damage of a pine forest (*Pinus thunbergii*) caused by the pine wood nematode along the coast of the Sea of Japan, Yamagata Prefecture (Photo credit: Y. Mamiya, Tamagawa University, Japan)

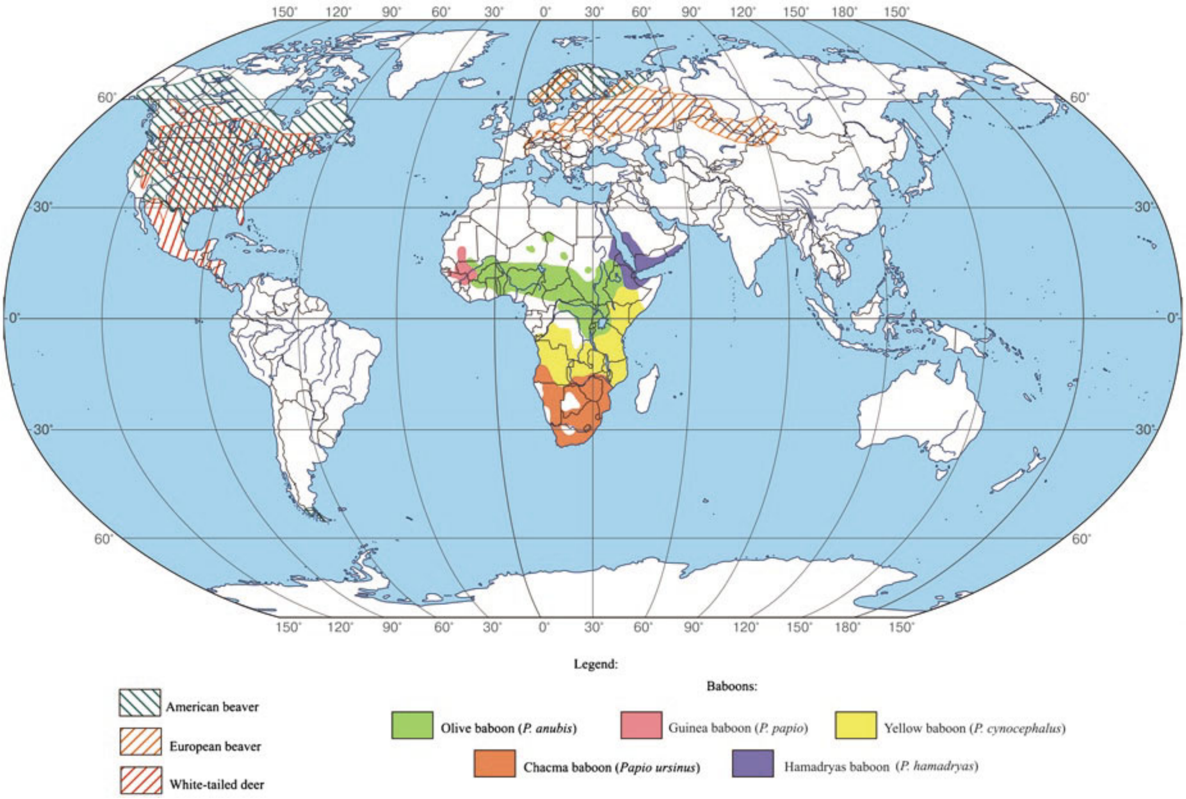

Fig. 5.6 Global distribution of some mammals – forest pests (Adapted from http://commons.wikimedia.org/wiki/file:American_beaver_map.png; http://ru.wikipedia.org.wiki; http://www.discoverlife.org/nh/tx/vertebrata/Mammalia/Cervidae/Odocoileus/virginianus/images/Odocoileus_virginianus_map.mx.jpg)

on different types of elm, beech, willow, maple and others. The flat scarlet mite (*Cenopalpus pulcher* Can. et Fanz) has been observed on hornbeam, alder, goat willow and plane trees (Bondarenko et al. 1993).

The mechanism and symptoms of the mites' impact on forest tree species are identical to those in effect on fruit trees. The damage to *leaves* caused by sucking mites leads to biochemical changes in the plant tissues. Initially, leaf spots appear and then, there is a change in their colour; later, they become dry and most of them fall. Loss of foliage causes reduced transpiration and, consequently, leads to a reduction in growth.

The impacts of nematodes and mites on forest tree species are illustrated by Photos 5.13 and 5.14.

5.2.3 Mammals and Birds

Mammals and birds cause damage mainly through *feeding*. The global distribution of some mammals considered to be forest pests is shown in Fig. 5.6. The main pests among mammals are *rodents* and *artiodactyls.*

Forest pests may include *many rodents*: mice, squirrels, jerboa, hares, gophers, porcupines, beavers, etc. Rodents gnaw tree roots, which often leads to the drying out of young trees. Small and spotted ground squirrels dig up and eat acorns. Many rodents eat the bark of trees (Bondarenko et al. 1993).

Hares damage trees by gnawing bark and eating around twigs and fine branches. Each hare eats 0.5 kg of food daily. Hares gnawed approximately 80% of willows and aspens aged 3–5 years on old scorched earth in the Russian Vologda region during the winter of 1936–1937 (Biology of woodland choir and beasts 1975).

Beavers also chew bark on branches and trunks. Each adult animal requires 700–800 g of bark daily (Dezhkin 1977). In addition, they damage forests in two ways: (1) by felling trees, and (2) by flooding

Photo 5.15 Among the harmful forest pests are murine rodents. Many of them feed on the bark of trees, which results not infrequently in their drying. The photo shows damage of trees due to mouse girdling in Minnesota (United States) (Photo credit: Robert L. Anderson, USDA Forest Service, Bugwood.org, 3 November 1970)

riparian forests. The annual cost of trees felled by North American/Canadian beavers (*Castor canadensis* Kuhl.) is estimated at US$60.70 per hectare in flood plain forests of Mississippi (United States). Losses are even higher from their 'hydraulic engineering' activities. In six southern U.S. states alone, the construction of beaver dams flooded 288,000 ha of forests. This corresponds to an annual damage cost of US$22 million (Conover et al. 1995).

The most significant *cloven-hoofed* animals are roe deer and other kinds of deer, elk and wild boar. Damage from different kinds of deer and elk is as *follows*: (1) eating buds and shoots (leading to disruption of new growth of the trees), (2) abrading of bark and gnawing (leading to decay of trunk at its base, dryness on its sides and toppling by wind), (3) eating leaves (reduces the assimilating surface of plants, slows growth and reduces transpiration) and (4) trampling (causes compaction of heavy soils, breakage of light soils, and weakens root respiration due to lack of oxygen).

Moose are a very serious forest pest in some areas of Eurasia. For example, one moose eats off an average of 412 trees and shrubs (1,740 shoots) in 24 h in the Leningrad region (Russia) in the first half of winter. Its daily diet is 10.2 kg in this case (Dezhkin 1977). The growth of the moose population resulted in decreases in pine plantations of 3.5 million hectares in southern Taiga in the European part of Russia from 1951 to 1978 (Anuchin 1991).

White-tailed deer (*Odocoileus virginianus*) cause the greatest damage in the north-eastern states of the United States. The total loss to Allegheny National Forest (Pennsylvania) caused by these deer was estimated at US$56.53 per hectare. The *total damage* estimate is US$367 million a year for the state forests in this region (6.5 million hectares) (Conover et al. 1995).

Roe deer (*Capreolus capreolus* L.) also cause significant damage to forest vegetation. These animals are becoming one of the main obstacles to reforestation in many countries of Western Europe. When the density of roe deer reaches 350 individuals per 1,000 ha, they completely consume the shoots and buds of young oaks (their favourite food).

Male roe deer also *rip the bark* off the tree trunks *with their antlers*, and the trees often die. For example, in southern Ural (Russia), at least 500 mutilated young birch trees were found in an area of 35 ha (Timofeeva 1985).

Photo 5.16 Beavers also chew on the bark of tree branches and trunks. Each adult animal requires 700–800 grams of bark daily. In addition, they damage forests in two ways: (1) by felling trees, and (2) by flooding riparian forests. The photo shows flooding of timber due to the American beaver (*Castor canadensis* Frazier) in the United States (Photo credit: Bill Godfrey, Georgia Forestry Commission, Bugwood.org)

In some regions, great losses are caused by *wild boar/pig (Sus scrofa L.)*, which expose and damage the *root systems of trees*. Demolition of roots by wild pigs in the southern United States leads to the death of pine seedlings (Spurr and Barnes 1984). Boar also destroys acorn crops. In several countries in Southeast Asia and Africa, *elephants* are serious forest pests; they eat the leaves and bark, destroying up to four trees/day (Heinrich and Hergt 2003).

Some *birds* are important pests also. *Crossbills (Frinfillidae)* and *nuthatches (Sittidae)* cause significant harm during their mass reproduction by eating nuts (Concomitant of forester 1990). Many birds feed on seeds. Some trees die from the effects of woodpeckers (Picidae) because of open slots in the bark. Birds also cause damage to the *vegetative parts* of trees and shrubs. *Capercaillie* (Tetraonidae) eat up more than 6 kg of pine or cedar needles in one winter month. *Grouse (*Phasianidae) and *hazel grouse* (Tetraonidae) eat buds off deciduous trees and shrubs in winter (Biology of woodland choir and beasts 1975).

Many species of forest birds use living branches of trees and shrubs to build their *nests*. In 1946, for example, *rooks* (*Corvus frugilegus*) built more than 6,000 nests in Askania-Nova parks (Ukraine); each nest consisted of 270 branches on average, 37% of which (600,000 young shoots) were alive (Inozemtsev 1987).

In the states of Washington and Oregon (United States), the damage caused by wild animals has reduced the survival of newly planted Douglas fir trees by 20%, their heights by 24% and the survival and heights of yellow pine by 31% and 22%, respectively. The total *damage from wild animals* was estimated at US$118 million for Douglas fir and US$378 million for yellow pine planted on 158 ha of land (Conover et al. 1995). In Germany, the Kempen forest loses 60–70 DM/ha/year due to barks being ripped by ungulates. It is believed that these losses are applicable to 10% of mountain forests in the country (Environment 1999, vol 2).

The negative impacts of mammals and birds on forests are illustrated by Photos 5.15–5.18.

Photo 5.17 In a number of regions, elephants do essential damage to forest vegetation. They break off and eat young branches, trample regrowth, and fracture mature trees. The photo shows trees damaged by African elephants (*Oxodonta africana* Blumenbach) in Kenya (Photo credit: Kennerth M. Gale, Bugwood.org)

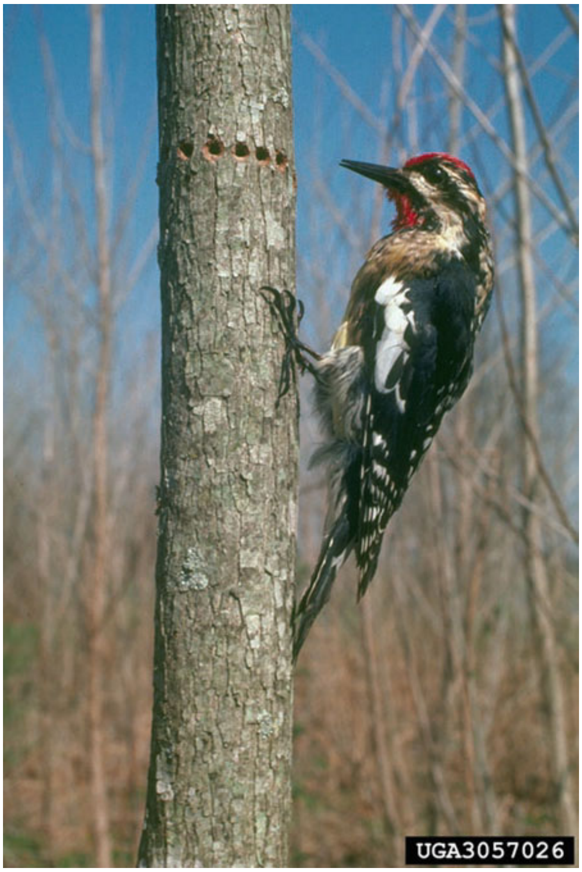

Photo 5.18 The impacts of bird pests on trees are varied. Some of them cause significant harm during their mass reproduction by eating nuts and seeds. Birds also cause damage to vegetative parts of trees and shrubs. Some trees die from the effects of woodpeckers (Picidae), because of the formation of open slots in the bark. The photo shows a yellow-bellied sapsucker (*Sphyrapicus varius varius*) (Photo credit: James Solomon, USDA Forest Service, Bugwood.org)

5.3 Plant Diseases

A *plant disease* is a disruption of normal metabolism that occurs under the influence of pathogens or adverse environmental conditions and leads to lower productivity of plants or their destruction. *Phytopathogens* are agents of plant diseases. The diseases caused by living organisms are usually referred to as *infectious* or parasitic. They can spread from diseased plants to healthy plants through the distribution of pathogens. *Non-infectious diseases* are caused by adverse abiotic factors (drought, frost, pollution, etc.), and they are not transmitted from one plant to another (Krutov and Minkevich 2002).

Pathogens of infectious diseases include fungi, bacteria, mycoplasma, viruses and higher parasitic flowering plants. Pathogens take nutrients and water from plants in the process of development, leaving toxins and other substances that are poisonous to plant cells and cause their death. All of this leads to the inhibition of plant growth, reduction of their productivity, or death (Shevchenko 1978).

The interaction between the phytopathogen and the host begins the moment the phytopathogen has penetrated into the tissue of the host plant. *Physiological* and *biochemical changes* that emerge in a *diseased plant* are as follows (Popkova 1989): (1) disruption of the water balance (dehydration of tissues as a result of damage to the roots or vascular system and increased transpiration due to damage to the superficial tissues); (2) weakening of photosynthetic activity caused by a reduction in leaf surface due to withering of leaves, proliferation of fungal mycelium and other effects; (3) disorders of carbohydrate metabolism (disease activates redox processes that lead to increased consumption of carbohydrates); (4) changes in nitrogen metabolism (changes in nitrogenous substances of the host plant occur under the influence of disease) and (5) respiratory disorders (at the beginning of the disease, it is significantly increased and, subsequently, decreases).

Infection is considered to exist from the time infiltrated infectious agents begin to multiply in the plant tissues. For successful infection, a certain *mass of infection* is required, which varies greatly depending on the pathogen. For example, a single spore of the fungus *Erysiphe graminis* (DC) can cause diseases of cereals with powdery mildew, while snow mould disease requires 10,000 spores of the fungus *Monographella nivalis* var. *nivlais* (Popkova 1989).

The development of an infectious disease occurs only in the presence of three major *factors*: (1) the pathogenic disease-causing organism, (2) a host plant that is susceptible to this disease and (3) an external environment that is conducive to the development of the disease (Shevchenko 1978). The most important role is played by environmental factors, especially the weather. Its action is manifested not in the predisposition of plants to disease but, more so, on the actual causative agent: its fecundity, distribution, incubation period and other characteristics. Of significant importance are the environmental conditions of growth of a phytocoenosis (plant community), human activities and other factors.

The most widespread and economically important plant diseases are *fungal diseases* (mycoses). The number of species of phytopathogenic fungi reaches 10,000 (Krutov and Minkevich 2002). Spores of fungi are specialized cells that serve for reproduction and dispersion. They are distributed by the following *factors*: (1) wind, (2) water, (3) insects, (4) animals and (5) people.

Most spores spread by *air flow*. Because of their lightness and their use of cilia, transport distances can reach tens and even hundreds of kilometres. Distribution of spores with *water* occurs during flooding or ruff-off of plants. *Insects and animals* carry spores of fungi on their bodies. These include a number of beetles (cambium beetles, bark beetles, liber eater, etc.), earthmovers, farm animals, livestock, wild ungulates and birds. *Humans* contribute to the spread of fungal infections by carrying spores on soil processing gear during agricultural activities, pruning and other activities (Shevchenko 1978).

Factors promoting the spread of *bacteria* that cause bacterioses are the same as in the case of fungal infections. The difference lies in the fact that water plays a crucial role. *Mycoplasma* is a special type of bacteria in which there is a plasma membrane instead of a cell wall (Biological encyclopaedic dictionary 1986). All mycoplasmal diseases are transmitted by cicadas (Cicadidae). Some of the symptoms of infection are chromate colour; curly, small leaves; and double flowers (Shevchenko 1978).

Carriers of *viral diseases* are usually insects with sucking stomatic bodies (aphids, cicadas, thrips, bugs

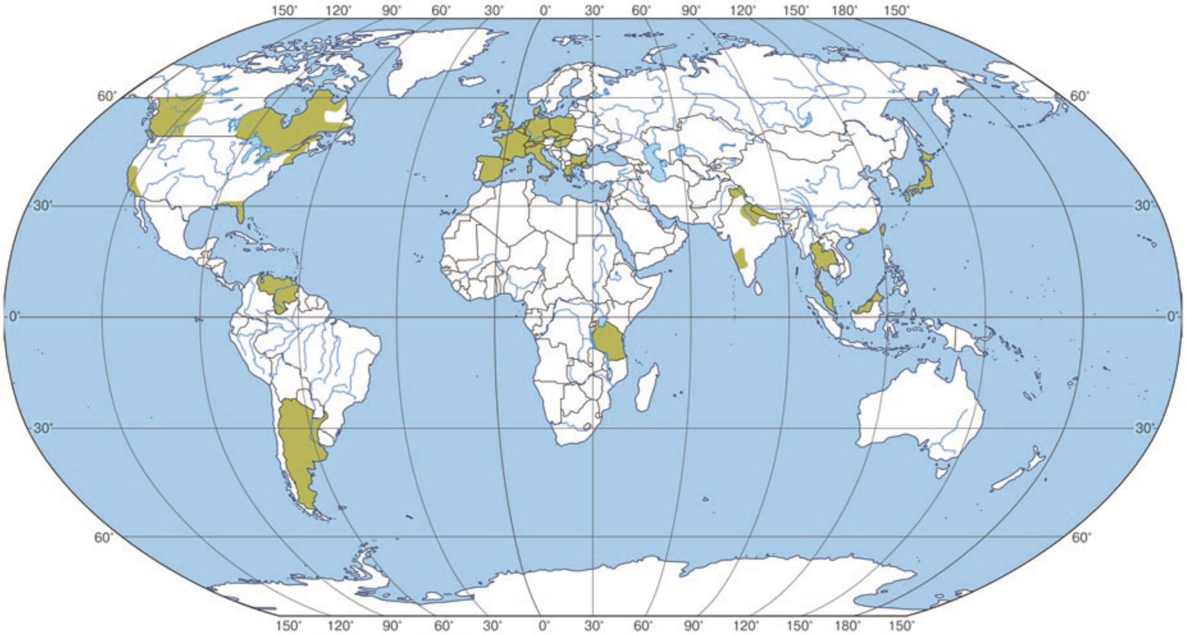

Fig. 5.7 Global distribution of powdery mildew on tomato caused by *Oidium neolycopersici* (Adapted from CABI Distribution Maps of Plant Diseases. Map No. 1000, April 2007. Copyright CAB International, Wallingford, UK); www.cababstractsplus.org/dmpd. Reproduced with permission of CAB International)

and others) that feed on cell sap and leave the virus behind. The diseases caused by viruses usually are chronic diseases (Shevchenko 1978).

There are a small number of species among the higher flowering plants that can live on other plants, causing their illness. Such plants are attached with suckers to the roots, stems, branches and other structures of their hosts and absorb their nutrients. All *flowering parasites* reproduce by seeds, which in some cases are distributed by birds. The diseases caused by *lichens* are usual for trees, and the damage they cause is minor.

Non-infectious diseases develop due to unfavourable environmental conditions. There is a metabolic disorder that leads to pathological changes in plants. These diseases are not transferable to other plants, but they weaken resistance to infectious diseases and may be the main cause of their occurrence (Protection of forests against pests and diseases 1988).

Typically, disease affects individual plants in a population. Such diseases are called *scattered*. However, sometimes a disease takes on a massive character and causes *epiphytotics*. The *criteria* for evaluation of its intensity are: (1) the frequency of disease (number of infected plants in a particular area or the number of hotbeds of the disease in a particular plant), (2) mortality (number of dead plants in relation to their total number), (3) lethality (number of dead plants in relation to diseased specimens) and (4) the degree of yield reduction of infected plants (Zhuravlev and Sokolov 1969).

Diseases of agricultural plants and forest trees are discussed below.

5.3.1 Agricultural Plant Diseases

Fungi are the most numerous pathogens of agricultural crops. There are more than 350 known species of toxigenic fungi that affect crops (Monastyrsky 2002). The global distribution of powdery mildew on tomato caused by the fungus *Oidium neolycopersici* is shown in Fig. 5.7. *Rust* (*Uredinales*) and *smut* (*Ustilaginales*) fungi are among the most significant in terms of their pathogenicity.

Stem rust (*Puccinia graminis* Pers.) *of wheat* is the most famous and economically important disease. Its

Photo 5.19 Black rot, caused by *Guignardia bidwellii* (Ellis) Viala & Ravaz, is a fungal disease of vines that affects primarily grape berries but also occurs on leaves and sprouts. This disease does huge damage to viniculture in the United States, France, Italy and Hungary. A bunch of grapes affected by black rot is shown (United States) (Photo credit: Clemson University, USDA Cooperative Extension Slide Series, Bugwood.org)

harmfulness is manifested in the disruption of the plants' water balance by increasing transpiration, reducing photosynthesis, lowering the intensity of synthesis and outflow of carbohydrates, and delaying the growth and development of the plant. The disease leads to a dramatic reduction of baking qualities of grain, in addition to shortages of the crop (60–70%) (Diseases of arable crops 1989).

Crop *losses* are enormous in years of *epiphytotics*. The disease in 1916 led to losses of 4,950,400 ton (38%) of the potential yield of wheat in the United States. Outbreaks in 1953 and 1954 destroyed 65% and 75% of the yield of hard wheat, respectively. Yield losses of winter wheat reached 938,400 and 870,400 ton because of epiphytotics in 1961 and 1962 in Kansas and Nebraska (Diseases of arable crops 1989).

Corn smut (Ustilago maydis) is among the most harmful of diseases as well, resulting in the death of young infected plants and infertility of corn cobs. Crop losses can reach 60% or more because of blister smut (*Entyloma dactylidis*). In 1970, all sown areas were affected by this fungus in the United States. The losses exceeded US$2 billion as a result (Our common future 1989).

Phytophthora of potatoes *(potato blight)* is a very dangerous disease. Its agent is the fungus *Phytophthora infestans* (Mont.) de Bary. The impact of the pathogen leads to the formation and rapid growth of stains on leaves, which later rot or dry up. Reduced assimilating leaf surface affects the accumulation of nutrients in tubers. Potato harvest shortfalls of 70% or more occur in severe cases of foliage damage (Diseases of arable crops 1990).

History has many examples of cases when *epiphytoty of phytophthora* led to real disasters, literally affecting the fate of nations. Cases of mass destruction of potato crops were recorded at first in Western Europe in the 1830s; they were directly related to this disease. In 1843, the disease had a catastrophic nature. In 1845 and 1847, it struck almost all the potato fields in the United Kingdom, Belgium, France, western Germany and north-western Russia. However, the *country most affected* was *Ireland*, where people were fed almost exclusively on potatoes. Famine and starvation caused the deaths of one million people, and two million were forced to emigrate to the United States in 1847 (Popkova 1989).

There are fewer bacterial diseases of crops than fungal diseases. Only 100 of 1,600 known bacterial species might cause plant diseases (Protection of plants

Photo 5.20 Witchweed (*Striga* spp.) is a parasitic plant that can infest agricultural crops. Corn, sorghum and sugar cane crops affected by witchweed in the United States have an estimated value well over $20 billion. Furthermore, witchweed is capable of wiping out an entire crop. The photo shows damage to corn due to witchweed in the United States (Photo credit: USDA APHIS PPQ Archive, Bugwood.org)

against diseases 2001). The diseases caused by bacteria can be reduced to the following basic *types*: rot, burn (necrosis), fading, spotting and cankers.

Bacterioses inflict significant damage to agriculture. For example, *fire blight, a casual pathogen (Erwinia amylovora),* attacks 167 species of fruit trees from 28 genera; apple and pear trees are particularly highly susceptible. The disease has produced devastation in many countries numerous times (Bacterioses of plants 1979).

Fire blight of rice is widely known and has spread worldwide wherever rice is grown. Its harmfulness is manifested in the reduction of seed germination, seedling mortality, and thinning of crops. Blight of rice reduces yields by up to 50% (Diseases of arable crops, vol 1 1989). The *citrus canker* is another example. An epiphytoty was recorded in 1914 in areas of the United States located on the Gulf Coast, in the states of Florida, Mississippi, Louisiana, Alabama and Texas. As a result, Florida alone had to uproot some three million trees (Bacterioses of plants 1979).

Viral diseases are caused by approximately 600 phytopathogenic viruses, and the losses caused by them amount to approximately 20% of the total economic damage from all groups of pathogens (Protection of plants against diseases 2001). Viruses cause the development of mosaic leaves, jaundice, rosette disease, curl, dwarfism and other diseases. For example, more than one million peach trees were destroyed in the United States due to *jaundice and short ovary cuttings*; more than 18,000 ton of tobacco is lost due to tobacco mosaic virus annually.

Mycoplasmal diseases of plants are quite rare. *Stolbur* is an example, and it is one of the most harmful and widespread diseases of solanaceous crops. Principal economic hosts are tomatoes, potatoes and eggplant. It is an obligate parasite of plant phloem, causing fruit quality to deteriorate, and it creates partially severed leaves. Disease outbreaks seem to occur in cycles, being favoured by hot, dry summers that stimulate vector migration. Tomato crops were reduced by 30–40% because of this disease (Diseases of arable crops 1991).

Flowering parasites do not cause very many diseases in general. The most dangerous flowering parasites belong to the genus *Cuscuta,* commonly

Photo 5.21 Citrus canker is a disease affecting citrus species that is caused by the bacterium *Xanthomonas axonopodis*. Infection causes lesions on the leaves, stems and fruit of citrus trees, including limes, oranges and grapefruit. While not harmful to humans, canker significantly affects the vitality of citrus trees, causing leaves and fruit to drop prematurely; a fruit infected with canker is safe to eat but too unsightly to be sold (Photo credit: http://en.wikipedia.org/wiki/Citrus_canker)

known as dodder. It is parasitic on a wide variety of plants, including a number of agricultural and horticultural crop species. For example, dodder infection led to a shortage of alfalfa seed crops by up to 80% or more (Protection of plants against diseases 2001). Dodder ranges in severity based on its species and the species of the host plant, the time of attack, and whether other viruses are also present in the host.

The possible *consequences of diseases* of agricultural plants might be the *following* (Popkova 1989): (1) the shortage of a crop; (2) reduction of product quality and (3) increases in losses in storage. Causes of *yield reduction* vary: (1) death of individual plants; (2) reduction of the assimilation surface of leaves; (3) inhibition of plant growth and others. *Decreased quality of products* is manifested in ugly fruits with spots on them. It deteriorates their presentation, technical, or edibility qualities; leads to cracking and deterioration of the quality of seeds and other effects. It also *reduces the keeping quality* of products in storage. They rot, fade and have greater susceptibility to pests due to the penetration of pathogens through the cracks.

Damage from diseases may be direct or indirect. *Direct* losses include all the consequences that manifest in reduced yield, deterioration of quality and reduction in the keeping quality during storage. *Indirect* losses include worsening of the quality of seeds obtained from infected plants. Planting is disrupted due to the repeated cultivation of seedlings and the costly work of uprooting and replanting fruit and berry crops, and farmers suffer a lack of income, during the period without fructification and other problems (Popkova 1989).

Diseases of crops lead to tremendous *economic losses* worldwide. An estimated US$33 billion of losses occur in the United States annually (Pimentel et al. 2001). The expenses involved with taking measures against pathogens during the period 1983–1990 accounted for US$156 billion annually, for dealing with vectors of pathogens, US$10 billion and for controlling parasites, US$12 billion (Akimova and Khaskin 1999).

The impacts of crop diseases on various branches of agriculture are illustrated by Photos 5.19–5.21.

5.3.2 Forest Plant Diseases

There is a wide variety of *forest diseases*. For example, in China, which is not the richest country in terms of forest resources, 2,924 forest diseases have been identified (Xu 2003).

Diseases of forest trees are similar to those of humans. They are *vascular diseases*, in which vessels are blocked in peripheral layers of wood; this condition stops the delivery of aqueous solutions from the roots to the crown and subsequently leads to shrinkage. The best-known vascular diseases are Dutch elm disease, vascular mycosis of oak, vascular wilt – which is typical for many hardwoods –, and others. The main causative agents of these diseases are fungi and, occasionally, bacteria (Zhokhov 1975).

Cankers are caused by fungi, bacteria, mechanical damage, and low temperatures. They damage the cambium, bark and outer layers of sapwood. They form deep and unhealed wounds on trunks and branches. Examples of such diseases are chestnut blight, aspen black canker (due to the fungal pathogen *Hypoxylon mammatum*) and others.

Necrotic diseases of trunks and branches damage the bark, cambium and sapwood, causing rapid death. This group of diseases includes dying of Weymouth pine (*Pinus strobus*) branches caused by *Brunchorstia pinea (Karst*) fungus. Death of poplar branches and trunks is caused by *Cryptodiaporthe populea* (Sacc.) Butin ex Butin, *Valsa sordida* (Nits.) fungi and others (Shevchenko 1978).

With regard to *pathogens*, the vast number of diseases of forest trees and shrubs are due to *fungi*.

Photo 5.22 The real honey agaric (*Armillaria mellea*) is better known as an edible mushroom. In total, it affects more than 200 species of plants. The damage from *Armillaria* is very great in many countries because the trees they affect eventually die. The hollows in the trunk caused by decay of wood due to this disease are shown (Photo credit: James Kimmey, USDA Forest Service, Bugwood.org)

The *second* most common pathogens are *bacteria.* They are followed by *viruses*, mycoplasma *organisms* and *flowering parasites*.

According to the parts of forest trees and shrubs that are stricken by disease, the following categories have been *identified*: (1) diseases of fruits and seeds, (2) diseases of leaves and needles, (3) diseases of branches, (4) trunk diseases and (5) diseases of roots (Zhuravlev et al. 1974).

Diseases of *fruits* and *seeds* are caused mainly by fungi. The fungus may occur during fruit and seed ripening on trees, or during harvesting, transportation and/or storage. The most common and *harmful diseases* include mummification, rust, deformation, musty rot and spotting (Handbook of forester 1980).

Diseases of *leaves* and *needles* are very diverse in nature and origin. The pathogens are fungi, bacteria and viruses. The most common and harmful disease of *needles* is blight, which is found in almost all conifers. Another common disease of needles is rust, caused by various representatives of the rust fungus. There is a widely known epiphytoty of white pine blister rust in north-eastern states of the United States, which has led to the death of thousands of hectares of forest (Azbukina 2005). Mildew is especially harmful among leaf diseases. It predominantly damages oak forests (Zhuravlev and Sokolov 1969).

Tree *branch* diseases are common to all kinds of trees. They are caused by fungi, bacteria, viruses and plant parasites. The most *common diseases* are branch canker, branch blows, tracheomycosis (*Gibberella xylarioides*), bark burn, drying branches, or distortion. These diseases lead to a drastic disruption of the physiological activity of trees. For example, canker of aspen, exacerbated by the bacterium *Pseudomonas remifaciens Koning*, reduces growth of stands by 20% or more (Protection of forest against pests and diseases 1988).

A well-known *branch pathogen* is the semi-parasitic plant mistletoe. In Poland, the mistletoe is considered to be one of the reasons for the disappearance of silver fir; in France, it reduces the growth in diameter and height of fir and poplar trees and in Austria, mistletoe inhibits growth and causes the death of oak (Anuchin 1991).

Trunk diseases are caused by fungi, bacteria and viruses. The *most significant* are *rots*, resulting from the introduction of infectious agents into trees through damaged bark. Rotting wood is caused solely by fungi (Protection of forest against pests and diseases 1988).

Fungal damage to plant vessels often leads to tree mortality. In terms of consequences, the most significant is *Dutch elm disease*. This disease has repeatedly reached the scale of epiphytoties. For example, it destroyed 800,000 elm, or 60%, of 1,228,000 trees in Belgium in 1918; it also killed 30% of the breed in the Netherlands in 10 years. There were two million affected elm trees in England in the 1970s (Krutov and Minkevich 2002).

The most damaging canker is *chestnut blight*. It is caused by the fungus *Endothia parasitica* (Murr.).

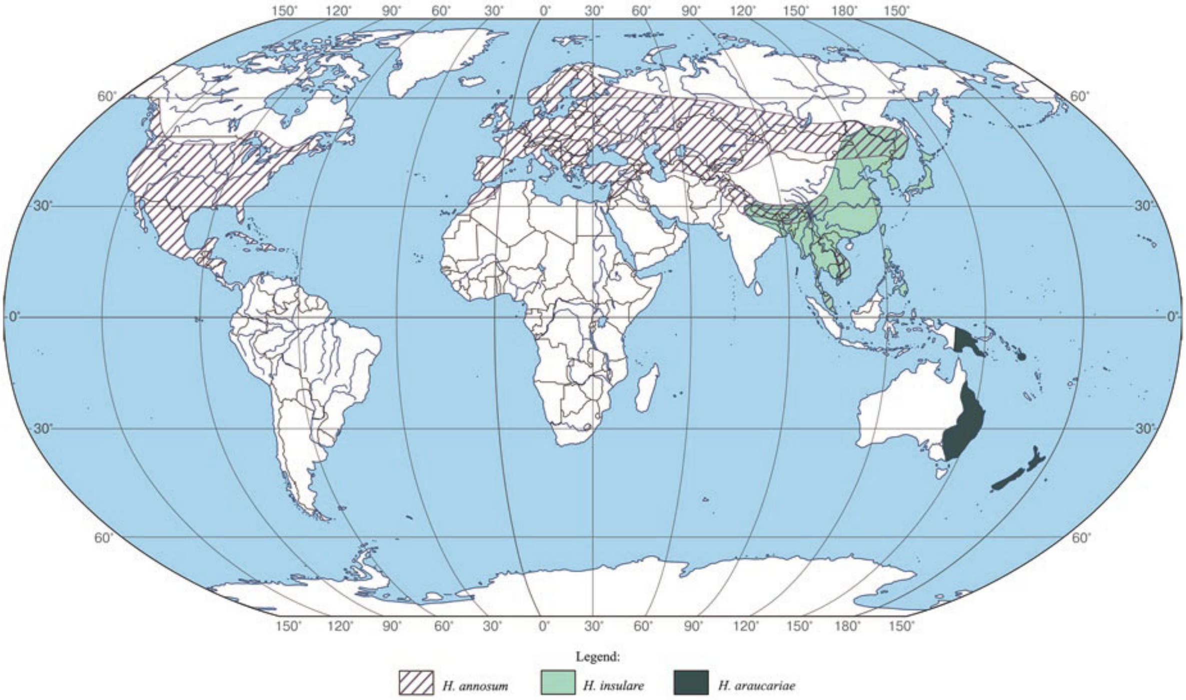

Fig. 5.8 Global distribution of root and butt rot caused by *Heterobasidion species* (The map is partly based on C.M.I. Distribution Maps of Plant Diseases. Map No. 271, Edition 3, 1980. Reproduced with permission of K. Korhonen. Finnish Forest Research Institute)

Photo 5.23 The forest plots affected by Armillaria root rots are usually well pronounced. The photo shows infection centres on a mountainside in the United States (Photo credit: Ralph Williams, USDA Forest Service, Bugwood.org)

Photo 5.24 Trunk diseases are caused by fungi, bacteria and viruses. The most common diseases are branch cancer, branch blows, tracheomycosis, bark burn, drying branches, or distortion. These diseases lead to a drastic disruption of the physiological activity of trees. The photo shows Fusarium canker on yellow poplar, with bark removed, in Ohio (United States) (Photo credit: Robert L. Anderson, USDA Forest Service, Bugwood.org)

This fungus caused severe epiphytoties in North America in 1904. Over several decades, it caused almost complete destruction of forests of the American chestnut (*Castanea dentata*) in the United States (Spurr and Barnes 1984). Later, the chestnut blight caused mass destruction of chestnut plantings in Italy, Spain, the former Yugoslavia and Switzerland (Shevchenko 1978).

Trunk bark necroses are characteristic primarily of hardwood (Handbook of forester 1980). Their hallmark is the formation of elongated bands along the trunk bark and sapwood, causing the tree to wither away. Bark necroses often lead to shrinkage of the crown or the entire tree. The agents are mostly fungi and bacteria that infect plants through areas of dead bark (Krutov and Minkevich 2002).

Among *root* diseases, rot is the most common. Roots are vital organs of plants. Their deterioration disrupts absorption of nutrients from the soil, which leads to weakening and gradual drying of the trees. The most dangerous pathogens of roots are annosum root rot (*Heterobasidion annosum* (Fr.) Bref.) and real honey agaric (*Armillaria mellea*).

Annosum root rot affects more than 25 species of plants, particularly pine, spruce, fir and juniper, often causing their mass drying (Protection of forest against pests and diseases 1988). This fungus is widely distributed (Fig. 5.8). The disease often leads to loss of forests in large areas. *The real honey agaric* (*Armillaria mellea*) is better known as an edible mushroom. In total, it affects more than 200 species of plants. The damage from *Armillaria* is very great in many countries because the trees they affect eventually die (Zhuravlev and Sokolov 1969; Protection of forest against pests and diseases 1988).

Diseases of forest plants and shrubs cause great *economic damage*. Annosum root rot (*Heterobasidion annosum*) alone is responsible for the loss of US$1 billion annually in the United States (http://en.wikipedia.org/wiki/Heterobasidion_annosum). Each year, diseases of forest plants lead to decreases in timber growth of 17 million cubic metres in China alone. The financial losses from forest diseases are estimated at five billion yuan (US$600 million) per year (Xu 2003). In Canada, approximately 850,000 cubic metres of lumber is killed due to diseases and pests each year (Sokolov 2008).

The effects of various plant diseases on forestry are illustrated by Photos 5.22–5.24.

5.4 Diseases of Animals and Humans

Disease is a disruption of vital activity. We consider here only those diseases that have a *natural origin*. These diseases are associated with the following *factors*: (1) geophysical; (2) geochemical; (3) related to peculiarities of food regimes, (4) caused by contact with poisonous plants and allergens of vegetable origin, (5) caused by contact with venomous and poisonous animals and animal allergens, (6) associated with infections and invasions caused by living agents or their toxic products and (7) injuries associated with the elemental forces of nature (Voronov 1981).

The *geophysical factors* include various meteorological processes (solar radiation, temperature and pressure changes, strong winds, etc.). We described such diseases and pathological states of organisms in the relevant sections of Chap. 3. Geophysical factors also include changes in solar activity and the Earth's magnetic field, and the regime of sunlight. Diseases and reactions associated with such fluctuations are discussed in Chap. 7.

Diseases and pathological conditions caused by biosphere *geochemical heterogeneity* are considered in Section 6.2. Microelementoses and other nutritional diseases – that is, diseases associated with the peculiarities of nutrition – are most dependent on social and ethnic factors that are beyond the scope of this publication. Therefore, we have not considered these diseases.

The diseases caused by contact with *poisonous plants* are addressed in Sects. 5.10.1–5.10.3. Diseases caused by *allergens* of plant origin are discussed in Sects. 5.14.1. Similarly, diseases associated with *venomous* and *poisonous animals* and *animal allergens* are considered in Sects. 5.8.1–5.8.4 and 5.14.2. Injuries and illnesses caused by *hazardous natural processes* are described to varying degrees in Chaps. 1–4. This section will discuss diseases of *group 6*. These are contagious diseases, which are characterized by sequential transfer of pathogens from an infected animal or human to a healthy one, either directly or indirectly, with the help of various environmental elements.

There are *four main ways* agents of diseases are transmitted: (1) through the digestive tract (alimentary), (2) through the respiratory tract (respiratory), (3) via a carrying agent (vector-borne) and (4) through the integument (without vectors).

The main modes of pathogen transmission correspond to four anatomical and physiological *organs*: digestive, respiratory, circulatory and outer integument. The most numerous (42%) diseases are those that are transmitted through the *alimentary* system, and transfer factors are infected food and water. *Inhalation* organs transmit 22% of infectious diseases. *Respiratory* infections are divided into dust and airborne infections. *Transmissible* diseases transmitted via the circulatory system account for 13% of all diseases, and diseases transmitted through skin account for 23% of all diseases (Manual for general epizootology 1979).

Diseases also can be divided on the basis of the infected individual. From this viewpoint, all diseases are divided into *three groups*: (1) zoonoses, (2) zooanthroponoses and (3) anthroponoses. The *first* group includes diseases that are unique to animals. The *second* group includes infectious and parasitic diseases that are common to humans and animals. The *third* group includes diseases that are unique to humans.

The ever-increasing *mobility* of people contributes to the spread of diseases. Earlier epidemics were broken off within the boundaries of settlements, whose inhabitants died out, and the survivors gained immunity. The spread of infections grew with the increasing mobility of the population. Now, the movement of people occurs globally in a shorter time than the incubation period of any infection.

There are extremely *large differences* in the *distributions* of various diseases. Some diseases are highly *localized*. For example, the natural focus of *Kyasanur forest disease* is only 1,500 km^2 in the Indian state of Karnataka (pre-1973, it was Mysore) (Manual for zoonoses 1983). Other diseases can be *quite localized* but at radically larger scales. Thus, *Rift Valley fever* is confined to the zone of the Great African Rift, stretching for 2,500 km from north to south, from Ethiopia to the mouth of the Zambezi River; it affects an area of approximately four million square kilometres (Tarshis 1988).

Slightly *larger distributions* occur with *American trypanosomiasis* (Chagas disease), which is found in most countries of South and Central America. Its main centres are located in Brazil, Argentina, Bolivia, Venezuela, Guatemala, Mexico, Paraguay, Peru, Uruguay and Chile (Great medicinal encyclopaedia, vol 27 1986).

Some diseases cover *several continents*. For example, *babesiosis* is distributed in Europe, South America, Asia and Africa. There is a ubiquitous distribution for such diseases as foot-and-mouth disease, Q fever, brucellosis, leptospirosis, salmonellosis, toxoplasmosis and trichinosis (Manual for zoonoses 1983).

The *most common disease* is *toxoplasmosis*, the spread of which is not limited by natural, climatic and geographical conditions. The agent of this disease is found in representatives of all kinds of wild vertebrate animals and all kinds of domestic animals. The total infected populations reached 60–90% in countries of

South America and Central Africa, 25–50% in Western Europe and North America and 5–25% in South and Southeast Asia. It is believed that toxoplasmosis has infected about one-fourth to one-third of the global population, but in most cases, the disease has a hidden character (Great medicinal encyclopaedia, vol 25 1985).

Widespread manifestation of an infectious disease is called a *pandemic* (in humans) and a *panzootic* (in animals). In these cases, there is a sharp increase of morbidity, and the disease spreads through several countries, or a whole continent or even several continents.

Historical examples of this form of disease manifestation are the *three* pandemics of *plague* in the sixth, fourteenth and nineteenth through twentieth centuries; *seven cholera* pandemics that occurred in the nineteenth through twentieth centuries and pandemics of *influenza* that were observed in the sixteenth, eighteenth and twentieth centuries (Great medical encyclopedia, vol 18 1982). Examples of *panzootics* are panzootic *scabies*, which struck all the horses of combating countries during the First World War (Parasitology and invasive diseases of livestock animals 1990). *Foot-and-mouth disease, swine fever* and *Newcastle disease* had panzootic character (Epizootology 1974).

The *basic parameters* used to characterize the intensity of the spread of a disease are the *incidence* (the ratio of the number of cases to the total number of people or animals); *mortality* (the number of victims that die from the disease among susceptible persons or animals in any group) and *lethality* (mortality expressed as a ratio of the number that die from the disease to the total number afflicted with it) (Manual for general epizootology 1979).

There are diseases to which *almost all animals* of a certain kind are susceptible. For example, anthrax, foot-and-mouth disease and rinderpest affect almost 100% of those animals that have not previously suffered from the disease or have not been vaccinated. However, a herd *will never be completely smitten* with salmonellosis, despite the possibility that all of the animals could have been infected. With listeriosis, the *incidence* ranges from 20% to 60%, with infectious bluetongue disease it is 50–60% and red nose of cattle *spreads widely* from 5% to 100% (Manual for general epizootology 1979).

Mortality from different diseases varies widely. It is low for various *helminths*; therefore, where a huge number of people are affected by them, the number of victims is insignificant. This rate is 0.004% for ascariasis, 0.01% for schistosomiasis and 0.25% for onchocerciasis. *Meningitis* and *Ebola haemorrhagic fever* are among the most dangerous diseases; the fatality rates are 50–80% and 60–80%, respectively.

There are environmental elements that are *sources* of disease. Usually, they are water, food, air and soil. The *first* element has an especially important role. Up to 90% of diseases that occur in developing countries are caused by a lack of clean water (Pimentel et al. 1999). We can identify *three groups* of diseases that are transmitted through water: (1) diseases transmitted by drinkable contaminated water, (2) diseases transmitted at external contacts with contaminated water and (3) diseases related to general hygiene.

The *first group* includes cholera, typhoid fever, amoebic dysentery, viral diarrhoea, infectious hepatitis and dracunculiasis (guinea worm disease). Worldwide, between 500 million and one billion children under 5 years old suffer from intestinal diseases alone every year. These diseases kill five million children every year (ReVelle and ReVelle, vol 2 1995). Diseases of the *second group* include schistosomiasis and leptospirosis primarily. The most common diseases of the *third group* are ascariasis and salmonellosis.

The impacts of diseases on livestock can be divided into *four categories* (Ramsay 1997): (1) death; (2) mass loss; (3) loss of fertility and (4) effects on lactation and fleece.

Damage from morbidity of people includes losses associated with mortality, damage caused by temporary or permanent disability and the costs of medical events (hospitalization, transport to hospital, outpatient care, epidemiological study of the hearth, disinfection, vaccination, medical examination of the foci, etc.).

Overall *financial losses* from diseases are extremely high. Global annual spending on combating human infectious diseases accounted for US$1,260 billion during the period 1983–1990; the struggle with their carriers, US$265 billion; and for pest control, US$42 billion. Similar costs for diseases in animals equalled US$210 billion, US$90 billion and US$64 billion per year, respectively (Akimova and Khaskin 1999).

The following sections cover zoonoses, zooanthroponoses and anthroponoses. It should be said that some of the diseases formally related to zooantroponoses are, in fact, not. For example, foot-and-mouth disease is a widespread dangerous animal disease, but recorded

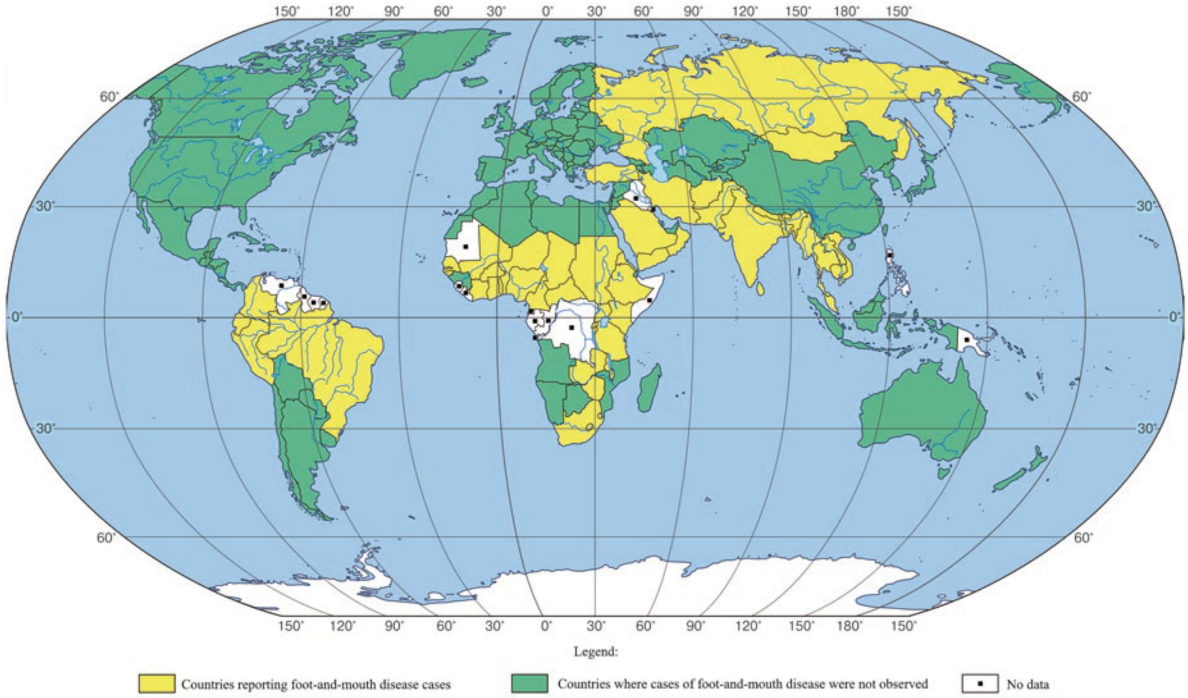

Fig. 5.9 (Global distribution of foot-and-mouth disease in 2004) (Adapted from https://www.llnl.gov/news/newsreleases/2006/NR-06-05-09.html; http://www.oie.int/eng/info/en_fmd2004.htm; http://nabc.ksu.edu/content/factsheets/category/Foot%20and%20Mouth)

infections of people are extremely rare, and they are usually benign and end in complete recovery (Great medicinal encyclopaedia, vol 28 1987).

5.4.1 Zoonoses

Zoonoses are infectious and parasitic diseases that affect only animals. They are divided into three *groups* (Epizootological dictionary 1976): (1) *ktenonozes* (diseases only of domestic animals); (2) *ktenoterionozes* (diseases of domestic and wild animals) and (3) *terionozes* (diseases of wild animals only).

The most dangerous disease is *foot-and-mouth disease* (FMD). The global distribution of foot- and-mouth disease in 2004 is shown in Fig. 5.9. It is typical for many animal species, and as mentioned above, it belongs formally to the zooanthroponoses. It is discussed in the section on zoonoses, however, due to the incompatibility of veterinary and medical injury. Foot-and-mouth disease is a *viral disease* that is characterized by the appearance of ulcers and blisters in the mouth and around the hooves of a sick animal.

Foot-and-mouth disease is a ktenoterionoz. Cattle are the *domestic animals most susceptible* to the disease, followed by pigs, sheep, goats and deer. Buffalo and camels are *less sensitive*. Dogs and cats become infected *very rarely* through milk. Horses and poultry are *not susceptible* (Epizootology 1974). Among *wild animals*, FMD affects mostly hoofed animals: elk, roe deer, caribou, antelopes, gazelles, wild goats, east Caucasian tur (*Capra cylindricornis*), yak and fallow deer (Manual for zoonoses 1983).

The *components of damage* due to FMD are (1) a complete cessation of lactation or reduction in milk yield, (2) reduction of traction effort, (3) loss of mass or reductions in weight gain, (4) death of young animals, (5) raising the age of grazing on pasture, (6) increase in feed intake, (7) miscarriage, (8) increase in calving interval, (9) reduction in the value of meat, and (10) infertility (Harrison 1996).

Photo 5.25 Mass mortality of Pacific sardine (*Sardinops sagax*) stocks occurred in the coastal waters of Western Australia from October 1998 till May 1999. The previously unknown pilchard herpesvirus affected gills, resulting in the mortality of 60–70% of the biomass. The picture was taken on the sand beaches near Esperance, the south coast of Western Australia. Here, fish mortality was 17,590 ton, or 74.5%. The beaches littered with dead fish disrupted the swimming season (Photo credit: Eric Laughton, Department of Fisheries, Western Australia, January 1999)

There were two relatively recent *outbreaks* of FMD. *One* was an epizootic that gripped Taiwan in March–July 1997. It extended to 6,147 pig farms and more than four million animals. All of them were destroyed, accounting for 38% of the country's pig population, and the damage amounted to US$10 billion (Elbers 2002). *Another* was an epizootic in 2001 in the United Kingdom, which lasted for 8 months, and four million animals of different species were killed, or 6.5% of the country's total livestock; the losses amounted to more than US$31 billion (Epizootic situation in the world 2003).

Another zoonotic disease affecting several species of animals is *theileriasis*. This is a seasonal disease that starts in the warm season, when ticks parasitize animal bodies. Damage from theileriasis is very significant. *Mortality* of animals may reach 40–80% of those that become sick. In cows, it causes reduced milk yield; in bulls, theileriasis leads to infertility (Parasitology and invasive diseases of livestock animals 1990). Along with *trypanosomiasis*, theileriasis is the main reason that the productivity of livestock in Kenya is the *lowest in the world*, although it has 160 million head of cattle and 286 million sheep and goats (Tarshis 1988).

Regarding the more specialized diseases, *rinderpest* is widely known, which, in the past, inflicted enormous damage to animal stock raising. In France and Belgium alone, rinderpest killed about ten million cattle from 1713 to 1796. *Losses* in Europe because of rinderpest occurred in the eighteenth century, when over 200 million head of cattle were killed or died. The disease killed two-thirds of the livestock in Africa in 1842; only buffalo survived (Tarshis 1988).

Classical swine fever is worth mentioning as one of the dangerous diseases affecting *pig breeding*. The *greatest losses* caused by classical swine fever have occurred in Western Europe, which accounts for 70% of the regular number of outbreaks in the world (Manual for general epizootology 1979). The record is an epizootic during 1997–98 in the Netherlands, which resulted in the destruction of 12.5 million pigs (out of 13.0 million); total losses amounted to about US$4 billion (Epizootic situation in the world 2003).

Among *sheep* diseases, *bradzot* is considered to be the most dangerous. This is an extremely acute bacterial disease characterized by haemorrhagic (i.e. with bleeding) inflammation of the mucous membranes of the stomach and duodenum and formation of necrotic foci in the liver (Stepanyuk and Litvin 1976). An infected animal sometimes dies within 10–15 min of the onset of symptoms (Biological encyclopaedic dictionary 1986). During outbreaks, bradzot strikes up to 15–20% of the population of unfortunate flocks, and mortality can reach 100% (Epizootology 1974).

Equine infectious anaemia is a disease of *horses*. This is a viral disease, the vectors of which are horseflies. Besides horses, it also affects ponies, donkeys and mules. The main pathological effects of the disease are destruction of red blood cells and suppression of the haematopoietic function of the bone marrow. The death rate for horses ranges from 20% to 80%.

The most important disease of *domestic birds* is *Newcastle disease*. It infects mostly birds of the chicken order, such as chickens, turkeys, guinea fowl, pheasants and peacocks. Pigeons, sparrows, magpies, parrots and hawks may also become sick (Epizootology 1974). The most important influences of Newcastle disease in poultry are (in descending order of importance): (1) the death of birds, especially youngsters; (2) the cost of vaccination and treatment; (3) mass loss and decrease in weight gain and (4) reduction in egg production (Harrison 1996).

Many cases of outbreaks of Newcastle disease are known in the history of bird breeding. For example, in 1966–1968 it gripped Indochina, as well as Japan, Iran and Iraq. In 1968–1971, a panzootic spread to Israel, Egypt, Jordan, Tunisia and through Greece and other Mediterranean countries throughout Western Europe. In late 1971, the disease penetrated into South America and the United States (Manual for general epizootology 1979).

Photo 5.26 The most dangerous disease among zoonoses is foot-and-mouth disease (FMD). Cattle are the domestic animals most susceptible to the disease. In some years, economic losses related to it number in the tens of billions of dollars. The photo shows cattle with FMD (Photo credit: University of Sydney, Australia. Image contributed by CSIRO Australian Animal Health Laboratory)

An *epizootic* in *pilchard* (*Sardinops sagax*) could be mentioned as an example of fish diseases, which happened off the coasts of Australia and New Zealand. The *first* large-scale epizootic in pilchard was recorded in March and September 1995. Fish kill was observed within 5,000 km of the Australian coastline and within 500 km of the New Zealand coastline. The reason for the death of the sardines was a herpesvirus, which was detected in the gills of fish 2–4 days before they died. Affected specimens die within a few minutes after the onset of clinical symptoms of respiratory distress. Fish kill from the disease progressed at a rate of 30 km/day (Jones et al. 1997).

A *second* epizootic was observed in 1998–1999. It spread to the whole Australian sardine habitat. Counting the numbers of dead fish gave the figures 17,590 ton in the three districts of the southern coast of Western Australia near the town of Esperance (photo), 11,193 ton in Bremer Bay and 144.4 ton near the coast of Albany (Gaughan et al. 2000; Gaughan 2002). It is believed that the Australian pilchard stocks decreased by 70% as a result of these outbreaks (Murray et al. 2001).

An indirect indicator of the amount of damage from zoonoses is an estimate that, due to diseases carried by *ticks* alone, *economic losses* of livestock amount to US$7 billion annually (Bolotin 1999).

The impacts of zoonoses on human activities are illustrated by Photos 5.25 and 5.26.

5.4.2 Zooanthroponoses

Zooanthroponoses are diseases that are common to humans and animals. They can be transmitted from animals to humans and vice versa. There are a much larger number of diseases whose causative agents can be transmitted from animals to humans; there are more than 200 known species (Manual for zoonoses 1983).

Domestic animals can be a *source* of the following diseases: brucellosis (cattle and pigs), anthrax (cattle, pigs and horses), Q fever (cattle), leptospirosis (cattle, rats and house mice), tuberculosis (cattle), rabies (cattle, pigs, horses and dogs), salmonellosis (pigs, horses, dogs, cats and poultry), trichinosis (swine), glanders (horses), plague (camels, rats and house mice), ornithosis (pigeons) and others.

Wild animals are a *source* of plague (marmots, ground squirrels and gerbils), tularaemia (rabbits, mice and water voles), epidemic haemorrhagic fever (red voles, field mice, etc.), leptospirosis (field mice and red voles), rabies (wolves, foxes, etc.), sleeping sickness (antelope), yellow fever virus (monkeys) and others.

According to etiological principles, all zooanthroponoses can be divided into the following *groups* (Manual for zoonoses 1983): (1) viral, (2) rickettsial, (3) chlamydial, (4) bacterial, (5) fungal, (6) protozoan, (7) helminthic and (8) caused by arthropods.

Zooanthroponoses of *viral aetiology* include influenza, rabies, several haemorrhagic fevers (yellow fever, Omsk haemorrhagic fever, haemorrhagic fever with renal syndrome, Lassa fever, Marburg fever, Ebola haemorrhagic fever, Dengue fever and others), many encephalitic diseases caused by viruses of different genera (Venezuelan encephalomyelitis of horses, tick-borne encephalitis, Japanese encephalitis, Kyasanur forest disease, West Nile fever, Rift Valley fever, California encephalitis, etc.), smallpox, monkey pseudocowpox and other diseases. The global distribution of Dengue fever is shown in Fig. 5.10.

Influenza is a viral disease that spreads in droplets of mucus through air when people cough, sneeze and talk. Birds are the natural reservoir of flu viruses. The most disastrous influenza outbreak was the pandemic of 1918–1920. It is believed that during this period it affected approximately 40% of the Earth's population. Figures on deaths caused by the disease are different, and they indicate 21.5 million, 24.7–39.3 million, or even 50 million (Johnson and Mueller 2002).

Rabies is a natural focal disease, and it is usually transmitted from animals to humans through a bite. The disease occurs almost everywhere. In different regions of the world, natural foci of rabies are supported by different kinds of animals. In European countries, the main reservoir of rabies virus is the fox; in the polar regions of Europe and America, it is the arctic fox; in the Middle East, it is the wolf; in North Africa, it is the jackal; in South Africa, it is the mongoose; in North America it is the coyote, skunk and raccoon and in South and Central America, it is the vampire bat (Manual for zoonoses 1983).

Approximately, one million farm animals *die* from this disease in South America alone every year (Great medicinal encyclopaedia, vol 3 1976). Between 90,000 and 100,000 animals are killed in Mexico annually (Medical theriology 1989). Up to *35,000 people* die worldwide from rabies each year according to the World Health Organization (Bertolini 2001).

Various forms of *encephalitis* take a prominent place among diseases of viral aetiology. *Japanese encephalitis* is a serious health problem for countries within the Asian continent. This is an acute infectious disease; it affects mainly the central nervous system and is transmitted by mosquitoes bred in rice fields. In addition to Japan, the disease is found in China, Korea, Vietnam, Cambodia, Malaysia, Singapore, India, Myanmar, Thailand, Indonesia, the Philippines and in the Far East of Russia (Manual for zoonoses 1983). Between 30,000 and 50,000 cases are registered annually. The fatality rate varies from 0.3% to 60% (Great medicinal encyclopaedia, vol 28 1986).

Rickettsial diseases occur worldwide, and they are divided into *five groups*: (1) the typhus group (e.g. rat or flea typhus), (2) the group of tick-borne spotted fevers (Marseilles fever, Rocky Mountain spotted fever, rickettsialpox and others), (3) the group containing only tsutsugamushi disease, (4) the group of Q fever, with a single nosological form only and (5) a group of paroxysmal rickettsial diseases (e.g. tick-borne paroxysmal rickettsiosis) (Great medicinal encyclopaedia, vol 22 1984).

Q fever is widely known, and it occurs in most countries of North and South America, Europe, Asia, Africa and Australia. Wild animals in natural foci are the source of infection. At least 96 mammal species and 60 species of birds have been identified as possible carriers of the Q fever infectious agent in nature (Manual for zoonoses 1983). The greatest outbreak of

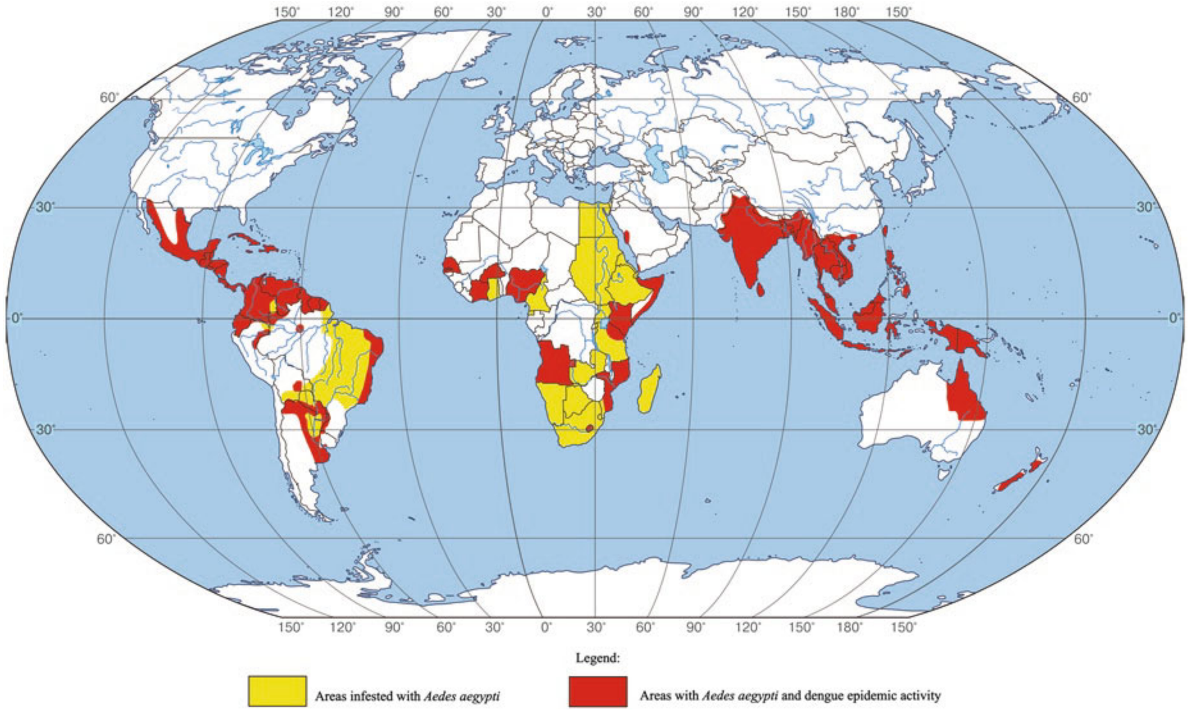

Fig. 5.10 Global distribution of Dengue fever (Reproduced with permission of Centers for Disease Control and Prevention (CDC))

Q fever occurred during the Second World War in Greece. It affected thousands of people during an epidemic in German troops and, later, in Anglo-American troops (Daniel 1990).

An example of a *chlamydial* zooanthroponosis is *parrot disease,* an infectious disease that spreads from birds to people primarily through the air. Parrot disease has global distribution. The causative agent was detected in 139 species of wild and domestic birds. Wild birds infect domestic ducks, turkeys and chickens through direct contact, as well as through pigeons, which leads to the emergence of epizootic diseases in poultry farms (Great medicinal encyclopaedia, vol 17 1981). Human infection usually occurs by aspiration, as well as by the alimentary route (Manual for zoonoses 1983).

Zooanthroponoses of *bacterial aetiology* include plague, anthrax, brucellosis, Lyme disease, salmonellosis, leptospirosis, glanders, tularaemia and many others. They are dangerous and widespread diseases. The most important disease is the *plague*. This is an acute infectious disease that has natural foci in 50 countries in Europe, Asia, Africa and America in the area between 50°N and 40°S (Great medicinal encyclopaedia, vol 27 1983).

The causative agent of plague is pathogenic to more than 200 species of rodents and lagomorphs. Its bacterium is transmitted by flea bites from sick animals to healthy ones and also to humans (Great medicinal encyclopaedia, vol 27 1986). There were *three pandemics* of the disease in world history. The *first* began in Egypt in AD 542; it lasted 50 years and claimed approximately 100 million lives (Daniel 1990).

The *second* pandemic began in 1346 in Crimea (Riklefs 1979). For 6 years, the disease spread to Egypt in the south, to Iceland in the north and to Spain in the west. It killed 30% of the 75 million people in Europe (Natural-science foundations of life stability 2003). The pandemic reached China and other countries by sea. It killed 75 million people worldwide (Daniel 1990).

The *third* plague pandemic began in Hong Kong in 1894 and was spread by ships to many port cities, while penetration of the disease into the mainland

Photo 5.27 Tularaemia (also known as Pahvant Valley plague, rabbit fever, deer fly fever) is a zooanthroponosis of bacterial aetiology. It is a serious infectious disease caused by the bacterium *Francisella tularensis* and distributed in North America and northern Eurasia. Besides humans, this disease is typical in aquatic rodents (beavers, muskrats) and terrestrial rodents (rabbits and hares). The disease is named after Tulare County, California. The photo shows a tularaemia lesion on the dorsal skin of a right hand (Photo credit: http://en.wikipedia.org/wiki/Tularemia)

Photo 5.28 Rabies is a natural focal disease, and it is usually transmitted from animals to humans through a bite. The photo is a close-up of a dog's face during late-stage 'dumb' paralytic rabies. Animals with 'dumb' rabies appear depressed, lethargic and uncoordinated. Gradually, they become completely paralysed. When their throat and jaw muscles are paralysed, the animals will drool and have difficulty swallowing (Photo credit: Barbara Andrews, Centers for Disease Control and Prevention, 1963)

interior was rare. The pandemic lasted for 10 years (1894–1903). The pandemic reached 87 port cities: Asia, 31 cities; Europe, 12; Africa, 18; North America, 4; South America, 15; and Australia, 7 (Great medicinal encyclopaedia, vol 27 1986).

Salmonellosis is a widespread and well-known disease in this group; it is characterized by lesions of the gastrointestinal tract. It occurs in most countries of the world, and it has caused epidemics as well as sporadic disease (Manual for zoonoses 1983). The degree of susceptibility of different people to salmonellosis is very different. Thirty percent of people get sick if they swallow between 100,000 and 10 million cells of Salmonella. Another 50% of people have to consume between 10 million and 100 million bacteria to get sick, and for the remaining 20%, it takes 100 million and 1 billion Salmonella bacteria to cause illness (Ehrhardt and Seguin 1984).

An example of a zooanthroponosis of *fungal aetiology* (mycoses) is trichophytosis (ringworm). It is distributed globally. Besides humans, it occurs in cattle and ruminants and in some wild animals (Great medicinal encyclopaedia, vol 25 1985). Animals and people are infected by direct contact with sick animals or as a result of dispersal of fungi in the environment. Skin injuries, scratches and abrasions contribute to the occurrence of trichophytosis (Epizootology 1974).

Zooanthroponoses of *protozoal aetiology* include diseases such as American and African trypanosomiasis, toxoplasmosis, babesiosis, leishmaniasis, coccidiosis and others. *American trypanosomiasis* (Chagas disease) occurs in most countries of South and Central America. It is believed that approximately 35 million people in South America are at risk of the infection, and approximately seven million people suffer from it (Tarshis 1988). In Brazil alone, Chagas disease causes the death of 5,000 people annually (Momen 2002). Among domestic animals, pigs, dogs and cats can become ill with trypanosomiasis and armadillos, opossums, monkeys, rodents and other animals can become ill with it in the wild.

African trypanosomiasis (sleeping sickness) is also very important, and it is characterized by bouts of fever, swollen lymph glands, increased sleepiness and

Photo 5.29 Plague is the most important disease. This is an acute infectious disease that has natural foci in 50 countries in Europe, Asia, Africa and America, in the area between 50°N and 40°S. This plague patient is displaying a swollen, ruptured inguinal lymph node, or bubo. After the incubation period of 2–6 days, symptoms of the plague appear, including severe malaise, headache, shaking chills, fever and pain and swelling, or adenopathy, in the affected regional lymph nodes, also known as buboes (Photo credit: Centers for Disease Control and Prevention, 1994)

central nervous system lesions. Vectors of the causative agent are the tsetse fly, which feeds on humans and animals. These flies are present in 36 countries, and approximately 35 million inhabitants are at risk of infection there (Tarshis 1988).

Sleeping sickness is prevalent only in tropical Africa, in the belt between 15°N and 29°S. About 10,000 people get sick there annually. Sleeping sickness ends in death if it is not treated (Great medicinal encyclopaedia, vol 23 1984). Sleeping sickness causes considerable damage to African livestock. African trypanosomiasis affects primarily Sudan, the Democratic Republic of the Congo, and Angola (Tarshis 1988; Gubler 1998).

Zooanthroponoses caused by worms (*helminths*) are numerous. There are 67 species of helminths that are common to humans and animals (Filippov 1988). Helminthiases have global distribution; the numbers of infected people and animals are in the hundreds of millions. They are prevalent mostly in tropical areas of Asia, Africa and South America (Great medicinal encyclopaedia, vol 5 1977).

Trichinellosis (trichinosis) belongs to the most important group of these diseases. More than 100 animal species are susceptible to it (Akbayev et al. 1992). Human infection occurs by eating raw, salted, smoked, or insufficiently processed meats, bacon and sausages. People face a higher incidence of trichinellosis in Southeast Asia and Central and South America (Gajadhar and Gamble 2000).

Trichinellosis was very widespread in the United States in the first half of the twentieth century. Sixteen percent of Americans (21 million people) were infected in 1940. Large infestations also took place in Argentina (12%) and Mexico (10%). Now, *the number of people infected with trichinellosis* is estimated at 11 million people worldwide (Dupouy-Camet 2000).

Schistosomiasis plays an important role also. This is a group of tropical helminthiases, characterized by lesions of the urogenital system and digestive organs. In tropical and subtropical countries, these diseases rank second after malaria in their socio-economic importance (Behram 2002).

The current area of distribution of schistosomiasis extends between 38°N and 35°S; it occurs in 73 countries (Great medicinal encyclopaedia, vol 27 1986). Approximately 500 million people are exposed and at risk of contracting the disease, and approximately 200 million people suffered from these helminths (Thirty years of UNEP 2003). This parasitic infection takes the lives of 200,000 people annually (http://www.bio-inform.ru).

Myiases are the last group of zooanthroponoses. They are caused by parasitism of the larvae of gadflies and other flies. Various types of *myiases* are ubiquitous, although human diseases are relatively rare. Examples of *myiases* include 168 reported cases in Conakry (Guinea) in 1975–1977, where the causes were different types of flies, and 14 cases in the city of Merida (Mexico) in 1974–1976 (Manual for zoonoses 1983).

The influence of zooanthroponoses on human activities is illustrated by Photos 5.27–5.29.

5.4.3 Anthroponoses

There are different classifications of *anthroponoses*. All human infectious diseases caused by organisms can be divided into *four groups* in accordance with the site of *localization of infection*: (1) intestinal infections (typhoid, dysentery, cholera, polio, etc.), (2) respiratory tract infections (smallpox, diphtheria, scarlet fever, whooping cough, measles, etc.), (3) blood-borne infections (malaria, typhus, relapsing fever, etc.) and (4) integumental infections (scabies, erysipelas, etc.) (Manual for general epizootology 1979).

In considering anthroponoses, we will use etiological principles, as we did in the previous section. *Viral* diseases include measles, smallpox, viral diarrhoea, and others. *Measles* is characterized by fever, intoxication, catarrh of the upper respiratory tract and mucous membranes of the eyes and rash on the skin. This is an extremely contagious disease; its contagious index (i.e. the index of susceptibility) is 95–96%. Virtually, the entire population could get sick if measles virus was brought to a place where, for a long time, there had been no epidemic. For example, a measles epidemic sickened 99% of the local population in northern Canada in 1952 (Farb 1971).

Smallpox used to be an important disease of viral aetiology. Epidemics have been repeatedly recorded in many European countries (France, Italy, Spain, Iceland, etc.). In some years, smallpox infected 10–12 million people in Europe, and the fatality rate was 25–40% (Great medicinal encyclopaedia, vol 17 1981). The first outbreak of smallpox was recorded in South America in 1507. During the sixteenth century, 2.5 million Indians died because of it on this continent alone (Kurbatova et al. 1997). In the years 1525–1526, an epidemic of smallpox destroyed almost the entire population of Incas (Sessa et al. 1999). The greatest spread of smallpox in the world happened in the eighteenth century.

Photo 5.30 Smallpox is an infectious disease unique to humans. It is also known by the Latin names *variola* or *variola vera*, which are derived from the Latin *varius*, meaning 'spotted', or *varus*, meaning 'pimple'. The term 'smallpox' was first used in Europe in the fifteenth century to distinguish variola from the 'great pox' (syphilis). This young girl in Bangladesh was infected with smallpox in 1973 (Photo credit: http://en.wikipedia.org/wiki/Smallpox)

The most famous anthroponosis caused by *rickettsia* is *spotted fever*, which attacks the central nervous system and blood vessels. Most epidemics of this disease occur in Africa: in the north (Egypt, Morocco, Tunisia and Algeria), east (Sudan and Ethiopia) and central (Democratic Republic of the Congo, Rwanda and Burundi) regions of the continent. Large outbreaks also take place in Asia and South America (Daniel 1990).

Lice are vectors of the causative agent of typhus. The largest typhus epidemic occurred during World

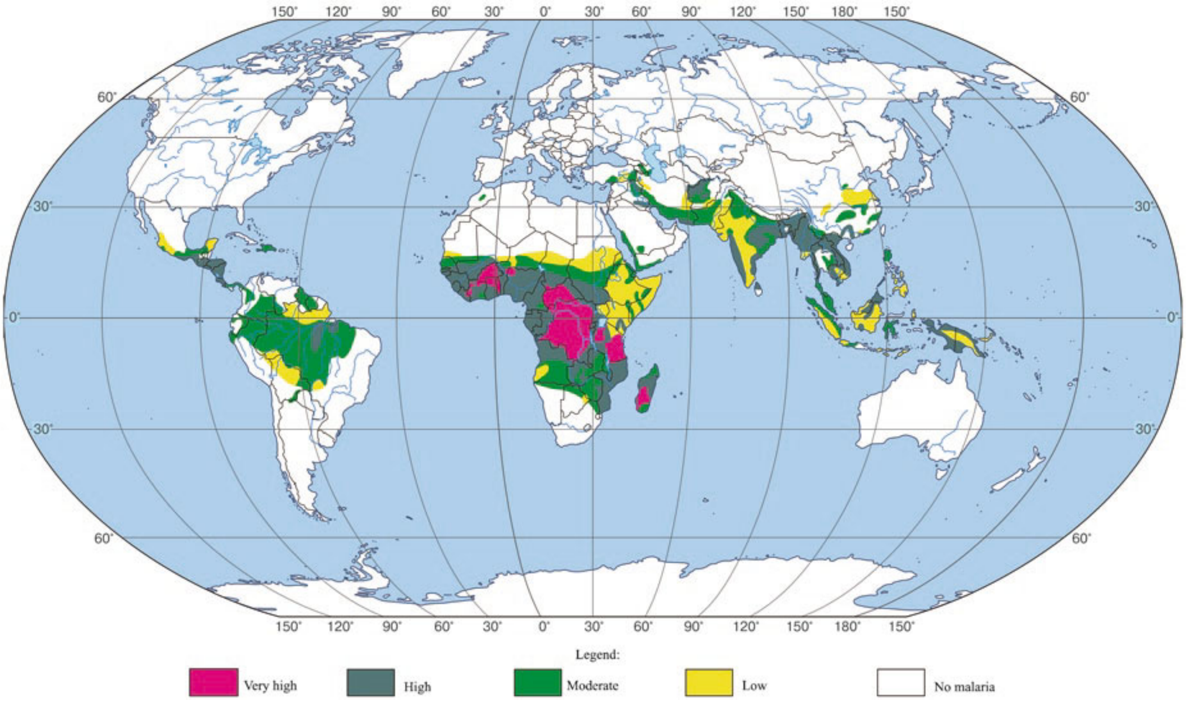

Fig. 5.11 Global distribution of malaria transmission risk, 2003 (Reproduced with permission of Roll Back Malaria Partnership)

War I. Approximately, 30 million people got sick in Russia and Poland at the time, 3.5 million of whom died. In the past, *mortality* reached 80% from typhus, while in our time, it has declined sharply to less than 1% due to antibiotics (Great medicinal encyclopaedia, vol 24 1985).

An example of an anthroponosis of *chlamydial* aetiology is *trachoma*. It is a chronic eye disease affecting the cornea and conjunctiva. Trachoma currently affects more than 500 million people (Great medicinal encyclopaedia, vol 25 1985). The number of people who have lost their sight because of it is estimated at six million people (Thirty years of UNEP 2003).

Anthroponoses of *bacterial* origin include cholera, typhoid, dysentery, legionnaire's disease, diphtheria, scarlet fever, whooping cough, erysipelas and many others. Cholera is the most dangerous of these; it is an acute disease characterized by lesions of the gastrointestinal tract, a disruption of water–salt balance and dehydration resulting from the loss of fluids and salts from faeces and vomit.

The Ganges and Brahmaputra Rivers are *foci of* endemic *cholera* in India. Worldwide, average deaths from cholera were 350,000–400,000 people per year during 1919–1949. The figure was 77,000 in 1950–1954, and in the following 5 years, it was approximately 40,000 people per year. In the past, in certain epidemics, mortality reached 50–60%; currently, this figure has decreased to 1% (Great medicinal encyclopaedia, vol 27 1986).

Microsporia (ringworm) is representative of *fungal* anthroponoses. This skin and hair disease is characteristic of many countries of Western Europe, the United States, China, Japan and India. A distinctive feature of the disease is that it is highly contagious; its typical feature is massive infection in schools, kindergartens, and other institutions (Great medicinal encyclopaedia, vol 15 1981).

Malaria should be recognized as the most important anthroponosis of *protozoal* aetiology; it is characterized by recurrent bouts of fever, enlarged spleen and liver, anaemia and various complications (cerebral oedema, acute renal failure, mental disorders, etc.).

The basin of the Congo River is considered to be the *malaria epicentre* of the planet (Newman 1989). The disease first spread from there to India, China,

Photo 5.31 This 2005 photograph depicts a female *Anopheles albimanus* mosquito feeding on a human host, thereby becoming engorged with blood. Like other species in the genus *Anopheles*, *A. albimanus* adults hold the major axis of the body more perpendicular to the surface of the skin when blood feeding. *Anopheles* spp. adults also generally feed in the evening or in the early morning when it is still dark. This species is a vector of malaria, predominantly in Central America (Photo credit: James Gathany, Centers for Disease Control and Prevention, 2005)

Photo 5.32 Dracunculiasis, also called guinea worm disease, is a parasitic infection caused by *Dracunculus medinensis*, a long and very thin nematode (roundworm). The infection begins when a person drinks stagnant water contaminated with copepods infested by the larvae of the guinea worm. Approximately 1 year later, the disease presents with a painful, burning sensation as the worm forms a blister, usually on a lower limb. A method used to extract a guinea worm from the leg of a human is shown here (Photo credit: Public Health Image Library #1342)

countries of Indochina, and then later to other regions. Currently, malaria occurs in more than 100 countries, where approximately 40% of the world population reside (Fig. 5.11). Zones of *highest risk* include Central America; some parts of South America, Haiti and the Indian subcontinent; Southeast Asia; the Middle East, and Oceania (www.cdc.gov/malaria/fag.htm).

Malaria has a tremendous impact on the *lives of people of many nations*. Approximately, 700 million people got sick annually in the early 1930s, seven million of whom died (Great medicinal encyclopaedia, vol 13 1980). Currently, the annual incidence is approximately 100 million people, and two million people die (Thirty years of UNEP 2003).

The most important anthroponoses of *helminthic aetiology* are ascariasis, onchocerciasis, dracunculiasis (guinea worm disease) and hookworm disease. *The first* of these diseases is caused by the roundworm *Ascaris*. It is believed that the ascarid *Ascaris lumbricoides* has invaded approximately 25% of the world's population; that is, more than 1.5 billion people (www.biosci.ohio-state.edu/ ~ parasite/ascaris.html).

Also, an important helminthiasis is *onchocerciasis*; it is distributed in all the countries of West and Central Africa, in Mexico, and in Central and South America. The vector of the causative agent is black gnats of the family Simuliidae; they breed on the banks of rivers and streams, which explains the second name of the

Photo 5.33 In certain regions of West Africa, onchocerciasis is a most important cause of blindness. In some villages it is common to see young children leading blind adults; in highly endemic areas, the blindness rate in men over 40 years old may be 40% or higher (Photo credit: World Health Organization, 17 November 2006)

disease: 'river blindness'. The disease has caused blindness in 30–40% of the adult population in some endemic areas. Blindness is due to the penetration of worm larvae (microfilariae) into the eyes, heavily damaging their tissues. In Africa alone, 30 million people suffer from onchocerciasis (www.biosci.ohio-state.edu/ ~ parasite/onchocerca.html).

Scabies is an example of an anthroponosis caused by *arthropods*. This is a parasitic skin disease caused by the mite *Sarcoptes scabiei*. Scabies is characterized by intense itching of the skin with the appearance of small, reddish nodules. Mites feed on the superficial layer of the skin, creating mines (these mines are approximately 1 cm long and have a wavy shape). Scabies can cause sleep disorders, neurological disorders, complications in the form of allergic dermatitis, and other problems (Great medicinal encyclopaedia, vol 27 1986).

The impacts of anthroponoses on human activities are illustrated by Photos 5.30–5.33.

5.5 Weeds

Weeds are unwanted plants on land and water areas that are used by humans in their economic activities. Terrestrial and aquatic weeds are considered separately due to large differences in the nature of their impacts on human activities.

5.5.1 Terrestrial Weeds

Weeds are characterized by a number of biological features that allow them to successfully compete with cultivated plants, despite all human actions to prevent this. The main *biological features of weeds* include the following: (1) extremely high fecundity, far superior to the reproduction of cultivated plants; (2) ability of seeds or fruits to spread far and wide by means of special devices; (3) ability to maintain long-term viability

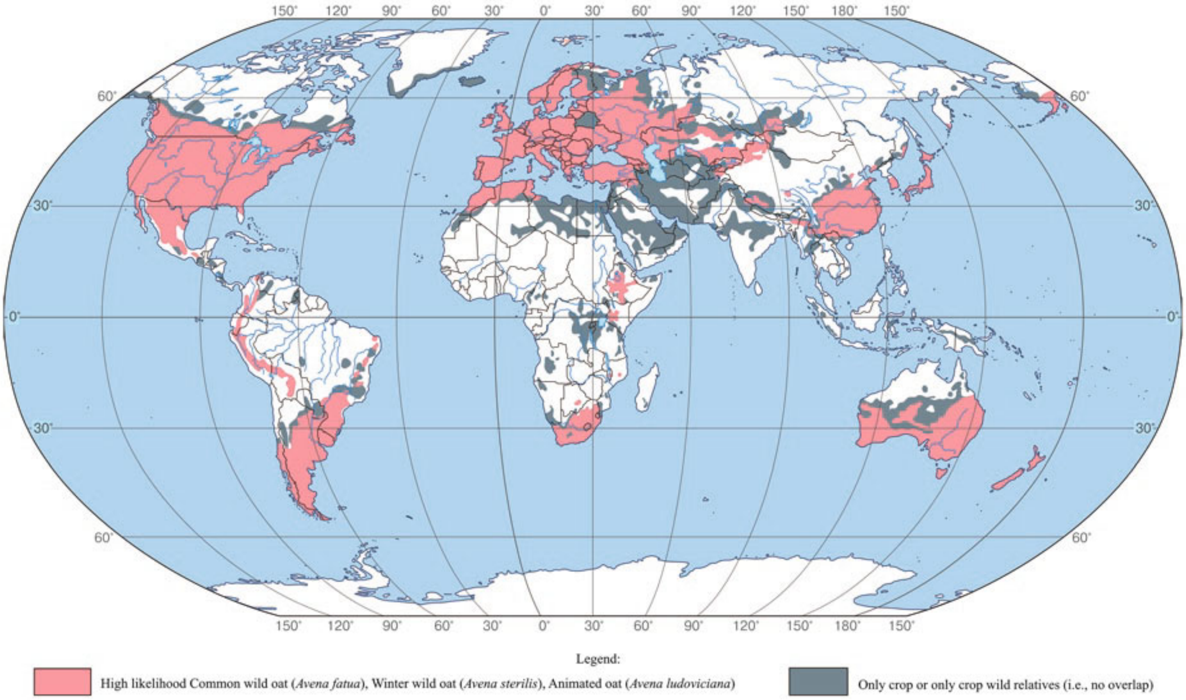

Fig. 5.12 Global distribution of wild oats (Adapted from http://www.eol.org/pages/1114782; http://www.agroatlas.ru/content/weeds/Avena_fatua/Avena_fatua_en.gif)

of the seeds in soil; (4) uneven seed germination (some weeds produce seeds with different stages of germination); (5) development of strong root systems with a large supply of nutrients; (6) active vegetative propagation of numerous perennial weeds; (7) seeds' ability to remain viable after passing through animal or bird intestines and (8) the continued ability of certain seeds to germinate in manure, water, silage and hay.

The main *impacts* of weeds on cultivated plants include the *following*: (1) competition for light (the leaves of weeds shade the cultivated plants and retard their development), (2) displacement of useful plants (due to their rapid and luxuriant growth, weeds always win out over cultivated plants in the fight for space), (3) competition for nutrients (especially nitrogen), (4) competition for water (many weeds use more water than cultivated plants), (5) decrease in soil temperature (due to its shading), (6) allelopathy (production of phytotoxins), (7) entwining around cultivated plants (creeping weeds encircle the stems of crops, flattening them), (8) promotion of the emergence of diseases (weeds are sometimes intermediate hosts of pathogens), (9) support of attack of insect pests (weeds are a place of temporary habitat and feeding of many insect pests and nematodes) and (10) the promotion of dissemination of rodents (thickets of weeds are convenient habitats for mice, voles, ground squirrels, hamsters and other species).

Weeds are divided into *two groups* according to *their lifespan* (Nikitin 1983): (1) 1- or 2-year plants and (2) perennials. In the *first group* of weeds, flowering and seed maturation occur only once, and then they fade. They include (1) annual, (2) biennial and (3) wintering plants. The worst *annual* weeds are wild oat (*Avena fatua*) and goosefoot, or white pigweed (*Chenopodium album* L.) (Isayev 1990). The global distribution of wild oats is shown in Fig. 5.12.

Fire rye (*Bromus secalinus* L.), curled thistle (*Carduus crispus* L.); hemlock (*Conium maculatum* L.) and others represent *biennial* weeds.

Examples of *wintering* weeds include common lady's purse (*Capsella bursa-pastoris*), louse (*Stellaria media*), the blue cornflower (*Centaurea cyanus* L.), henbane (*Hyoscyamus*) and Viola tricolour or pansy (*Viola tricolour*). Blue cornflower is the most nocuous,

Photo 5.34 Weeds are characterized by a number of biological features that allow them to successfully compete with cultivated plants, despite all human actions to prevent it. The seeds of the common dandelion (*Taraxacum officinale*) are capable of travelling great distances by means of seed-bearing parachutes. Photo taken 6 May 2009, New York, United States (Photo credit: http://en.wikipedia.org/wiki/Dandelion)

and it is the main weed of winter crops (Zhurba and Dmitriyev 2006).

Perennial weeds usually flower and fruit several times, and in addition to producing seeds, they reproduce vegetatively. They are classified into the *following groups* according to their biological features: (1) creeping-rooted plants, (2) rhizomatous plants, (3) taproot plants, (4) tuberous plants and root plants, (5) bulb plants and (6) plants with creeping and rooting on the ground stems.

Creeping-rooted weeds usually have extremely long roots that go from 3–5 to 10–20 m deep and have extensive branched systems with lots of buds. Even small fragments of these roots (3–5 cm or more) can produce new plants. Pink or sow thistle (*Cisium arvense* L.) is the worst weed of this type. It is able to produce a biomass of 3.6 ton above ground and 2.1 ton below ground on a 1 ha area, and it absorbs 138 kg of nitrogen, 31 kg of phosphorus, and 117 kg of potassium from the soil (Isayev 1990). Some other dangerous weeds of this group are field thistles (*Sonchus arvensis*), field bindweed or birch (*Convolvulus arvesis* L.), and common toadflax or wild flax (*Linaria vulgaris* Mill.).

From the *rhizomatous (rhizome)* weeds, the most harm to agriculture is caused by Johnsongrass (*Sorghum halepense*), couch grass (*Elytrigia repens*), Bermuda grass (*Cynodon dactylon*), yarrow (*Archillea millefolium*) and others.

Typical representatives of *taproot* (*rod-root)* weeds include different types of dandelion (*Taraxacum*), greater knapweed (*Centaurea scabiosa*), Turkish rocket (*Bunas orientalis*) and curly dock (*Rumex crispus*).

Tuberiferous and *rhizocarpous* weeds are less numerous and harmful. These include wild mint (*Mentha arvensis*), field mint (*Mentha austriaka*), marsh woundwort (*Stachus palusteris*) and others.

The representative of *bulbous* weeds is the widespread common plantain (*Plantago major*). *Creeping* and *rooting* ground weeds include creeping buttercup (*Ranunculus repens*), bloodroot goose (*Potentilla anserina*), ground ivy (*Glechoma hederacea*) and others.

Terrestrial weeds affect the following *types of human activity*: (1) crop production, (2) livestock raising, (3) food industry and (4) forestry and reforestation.

The impacts on *crop production* include the *following*: (1) reduction in yield (due to competition with cultivated plants because of life conditions), (2) deterioration of a crop's quality (seeds of many weeds are poisonous, have narcotic properties, or have a bitter taste), (3) difficulty in harvesting crops (tall, fleshy weeds clog combines and cutting machines and increase harvesting time), (4) increase in fuel consumption and amortisation of agricultural machinery (weeds with branching and thick roots increase traction resistance in soil and degrade the quality of ploughing) and (5) creation of conditions for propagation of pathogens, harmful insects and rodents.

The impacts on *livestock* are as *follows*: (1) threaten the life and health of livestock (grains and fruits of many weeds are poisonous, containing drugs or hispid, prickles, hooks, etc.; animals that eat them develop inflammation of the mucous membranes and respiratory paths and damage to their mouth and oesophagus) and (2) deterioration in the quality of animal products (e.g. various weeds give milk a bitter taste or clog the animal's wool).

The impact on the *food industry* is expressed in the complication of crop processing and deterioration of the quality of products obtained (different weeds are

Photo 5.35 Weeds influence cultivated plants in many ways (competition for light, displacement of useful plants, competition for nutrients, etc.). The weeds in the photo are choking out the sprouts of kidney beans in a Vladivostok suburb.Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 21 June 2007

difficult to grind grain into flour, give it a black colour, increase its moisture content, give it a bitter taste, etc.).

The impact on the forest *industry* and *agroforestry* is the creation of obstacles to the resumption and further development of cultured forest plants.

Losses from weeds are high. For example, in the former USSR, direct damage from weeds averaged 10.3% of the actual yield (Gruzdev 1980). In the United States, agriculture experienced similar losses, equal to 12%, which corresponds to losses of US$33 billion a year (Pimentel et al. 2001). Global expenditures on weed control were US$88 billion annually during 1983–90 (Akimova and Khaskin 1999).

The effects of terrestrial weeds on human activities are illustrated by Photos 5.34 and 5.35.

5.5.2 Aquatic Weeds

Aquatic weeds develop in lakes, reservoirs, rivers, irrigation and drainage canals and other water basins. All aquatic plants (including weeds) are divided into the following *groups* according to their biological characteristics (Khristoforova 1999):

1. Float on water surface in contact with water and air. They include *duckweed* (*Lemma* sp.), various kinds of *salvinia* (*Salvinia*), *European frog-bit* (*Hydrocharis morsus ranae*), *water hyacinth* (*Eichornia crassipes*) and others.
2. Immersed ('suspended') in contact with the aquatic environment only. This category includes some *pondweed* species (*Potamogeton*), *hornweed* (*Seratophyllum*), *pemphigus* (*Urticularia*) and *planktonic algae*. The most common is *Potamogeton*. This genus has approximately 65 species occurring in moderate climate zones throughout the world.
3. Submerged rooted related to water and soil, such as *American* or *Canadian waterweed* or *pondweed* (*Elodea canadensis*); *eelgrass*, *tape grass* or *vallis* (*Vallisneria spiralis*) and *whorled water milfoil* (*Myriophulum verticillatum).*
4. Floating on surface and rooted; that is, in contact with water, soil and air. These include the *water lilies* (*Nuphar*); *water lilies* (*Nymphaea*); some types of *pondweed*, the world's largest water lily (*Victoria regia*) and others.
5. Amphibian species that grow on shallow coastal waters; their stems and leaves usually rise substantially above the water surface. These are *arrowhead* (*Saggitaria saggitifolia*); different kinds of *cattails* (*Typha*); bulrush (*Scirpus*); *common water-plantain* (*Alisma plantago-aquatica*) and others.

An important feature of most aquatic weeds is their *fecundity*. Many of them reproduce by vegetative means in addition to reproduction by seeds. As they grow, they divide into separate parts, which later settle independently. Water fern/giant salvinia or kariba weed (*Salvinia molesta*) can double its number every 2.2 days

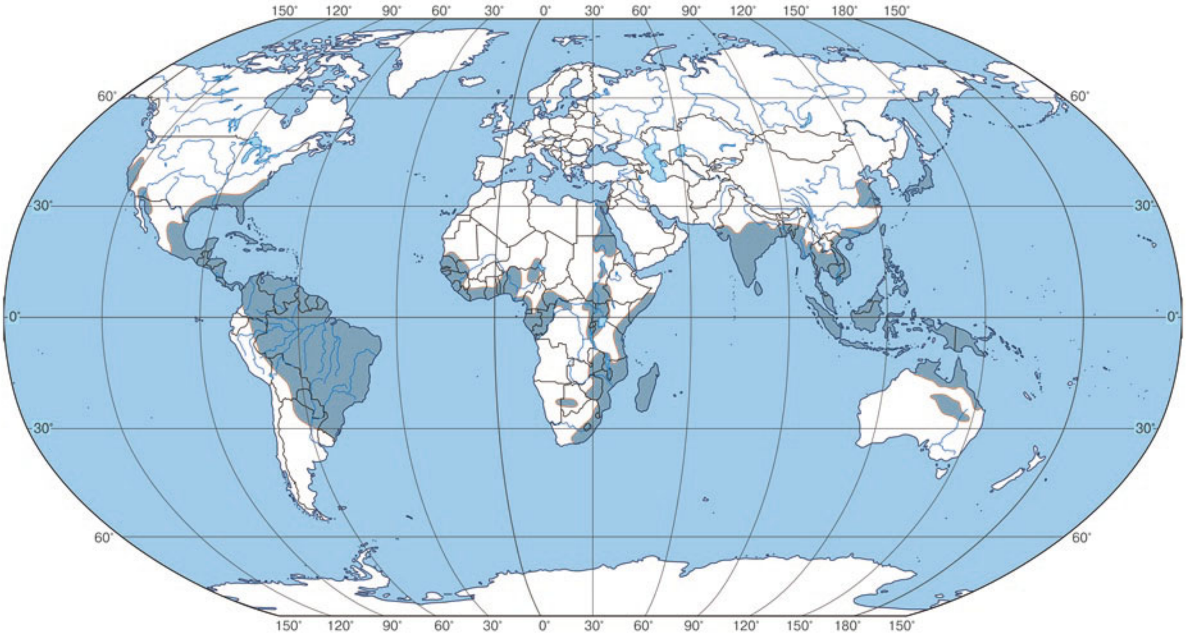

Fig. 5.13 Global distribution of water hyacinth (*Eichornia crassipes*) (Reproduced with permission of United Nations University Press)

under ideal conditions. If you put a single individual in water, in a month, there will be more than 8,000 plants, and after 2 months, 67 million (Mavrischev 2000).

The *water hyacinth* can reproduce year-round in the tropics, producing a subsidiary individual every 2 weeks (Human occupies Mother Earth 1997). A single plant outgrowth can cover a water area of up to 400,000 square metres in 10 months; each 100 m^2 will be populated by up to 450,000 plants (Khristoforova 1999). The global distribution of the water hyacinth (*Eichornia crassipes*) is shown in Fig. 5.13.

Aquatic weeds affect the following *types of human activity*: (1) shipping, (2) crop production, (3) fisheries, (4) hydropower generation, (5) water supply systems, (6) water transfers, and (7) recreational activities.

Mechanical resistance of plants is a factor affecting *water transport*. With growth, plants form big, thick cushions. For example, *kariba weed* can create such a cushion as large as 96 square miles (248.6 km^2) and 3-ft thick (i.e. 91.4 cm) (www.saj.usage.army.mil/conops/apc/salvinia.rdf). Navigation becomes impossible where development of such plants is particularly intensive.

The *water hyacinth* has a grand-scale impact on navigation. Because of it, shipping was stopped on some rivers in the southern states of the United States (Khristoforova 1999) and in several tributaries of the Congo River (Human occupies Mother Earth 1997). It significantly obstructs boating on the Congo River itself (Farb 1971), the Mississippi River (Nebel 1993) and several rivers in east Africa. The water hyacinth is also a serious problem for navigation on Lake Victoria.

Crop production is affected by aquatic weeds in such cultures as rice. Some of the reed maces are weeds in rice fields (Biological encyclopaedic dictionary 1986). Sometimes, giant salvinia (*Salvinia molesta*) has negative effects on rice. For example, annual seasonal flooding on the southern island of Kalimantan (Indonesia) brings weeds from the rivers and swamps into the lowland rice fields, which leads to their destruction (http://salvinia.er.usgs.gov/html/predicated_range.html).

Aquatic weeds significantly affect recreational and commercial *fishing*. A dense carpet of plants on the water surface greatly complicates or makes impossible the use of nets, seines and other fishing gear. Closed turf leads to reductions in fish stocks because it blocks the water–air interface and reduces oxygen content in the water, causing fish asphyxia (suffocation).

The impact is similar on *hydropower*, *water supply systems* and water transfers due to decreases in water

Photo 5.36 An important feature of most aquatic weeds is great fertility. Kariba weed (*Salvinia molesta*) can double their numbers every 2.2 days under ideal conditions. The photo shows the weed covering a farm pond, restricting commercial and recreational use and degrading aesthetics (Photo credit: Ted D. Centre, USDA Agricultural Research Service, Bugwood.org)

Photo 5.37 Aquatic weeds are also a serious problem for navigation. Milfoil plant is a submerged, perennial aquatic plant that grows in fresh inland water and fresh to brackish coastal waters. The photo shows milfoil plant on a boat motor on a Michigan lake (United States) (Photo credit: Michigan Sea Grant)

flow passing through the tight cushion of weed clusters. For example, the accumulation of water hyacinths blocks entrances to Owen Falls Dam, which leads to decreases in pressure and a reduction of power generation in Uganda and Kenya. In the city of Kisumu (Kenya), they reduce water supply in a local water inlet. The impact on *recreational activities* is due to the restriction of swimming and boating.

The economic *damage* from aquatic weeds is significant. In Florida (United States) alone, the fight against the giant salvinia (*Salvinia molesta*) costs US$30 million annually, and these costs do not include loss of income from tourism, shipping, fishing, and other activities (www.saj.usage.army.mil/conops/apc/salvinia.pdf). The annual expenditure is US$11 million for the fight against water hyacinths in Florida, Louisiana, and Texas (United States).

The impacts of aquatic weeds on human activities are illustrated by photos 5.36 and 5.37.

5.6 Bloodsucking Insects and Animals

The common characteristic of *bloodsucking insects* and animals is that they permanently or temporarily feed on the *blood* of humans and animals. The global distribution of some bloodsucking insects and animals is shown in Fig. 5.14.

Important members of the parasites considered are often called by the unifying term *gnat* (midge), which refers to a group of bloodsucking two-winged insects (black fly, midge, fungus gnat, biting midge, fruit fly and other small flies).

Different groups and species of bloodsucking Diptera, or midges, are closely linked to geographical areas. In general, mosquitoes and midges dominate in the *Arctic prairie (tundra)* zone; their total numbers are very high there, while the number of species is not. The species composition of midges is more variable in boreal forest *(taiga) and mixed forests*; the number of species includes not only mosquitoes and gnats but also slimies, horseflies and bloodsucking flies. *Farther south*, the species composition of midges decreases again; there are fewer species of mosquitoes, gnats, midges and horseflies, but sandflies are present (Tarasov 1996).

The effects of various kinds of gnats on *people* have their own characteristics, but in general, they are manifested in *loss of sleep* and *appetite*, sometimes with fever and the development of chronic ulcerative dermatitis. All this greatly affects the well-being of people and reduces their quality of life.

Effects on *animals* are similar. There is huge blood loss and disturbance, which in turn lead to problems such as reduced weight gain, productivity and resistance to diseases (Great medicinal encyclopaedia, vol 23 1984). There are frequent deaths of large numbers of animals related to massive attacks by midges (Parasitology and invasive diseases of livestock animals 1990).

Some bloodsucking insects, which are not midges, cannot fly. These include lice, fleas and bedbugs. *Head lice* are widespread throughout the world. Around 300 species are known (Biological encyclopaedic dictionary 1986).

Crawling over *animals*' bodies, lice inject substances that cause skin *irritation*, which is accompanied by *itching*. Strong lousiness disturbs animals; it disrupts their mode of nutrition. They lose weight and sometimes die. Their milk yields decline, and the quality of wool from sheep and goats deteriorates (Insects and ticks of the Far East 1987).

There are many known deaths of *people* from louse *seizure*. King Herod of Judea (73–74 BCE) died from intense pediculosis. Spanish King Philip II (1527–1598), the Roman dictator Lucius Cornelius Sulla (138–178 BCE), and others also died as a result of pediculosis (1990).

Fleas live at all latitudes of our planet. There are more than 2,500 species and subspecies of fleas in total. Significant draining of blood occurs with their mass attacks. For example, the female flea *Vermipsylla alacurt* sucks up to 100 mg of blood in 24 h, and there can be 700–7,000 of the parasites simultaneously on the body of a single sheep (Tarasov 1996). Sheep can lose 20% of their haemoglobin and 40% of their hair. Flea attacks on chickens will lead to a decline of 5–50% in egg production (Parasitology and invasive diseases of livestock animals 1990).

Female chigoe *fleas* or jiggers (*Tunga penetrans*) are the most significant, from a *medical point of view*. They inhabit the tropics of both the northern and the southern hemispheres. As they attack, they drill almost entirely into people's skin and remain there until the end of their life. They can reach the size of a pea, causing severe suffering to people (Great medicinal encyclopaedia, vol 3 1976).

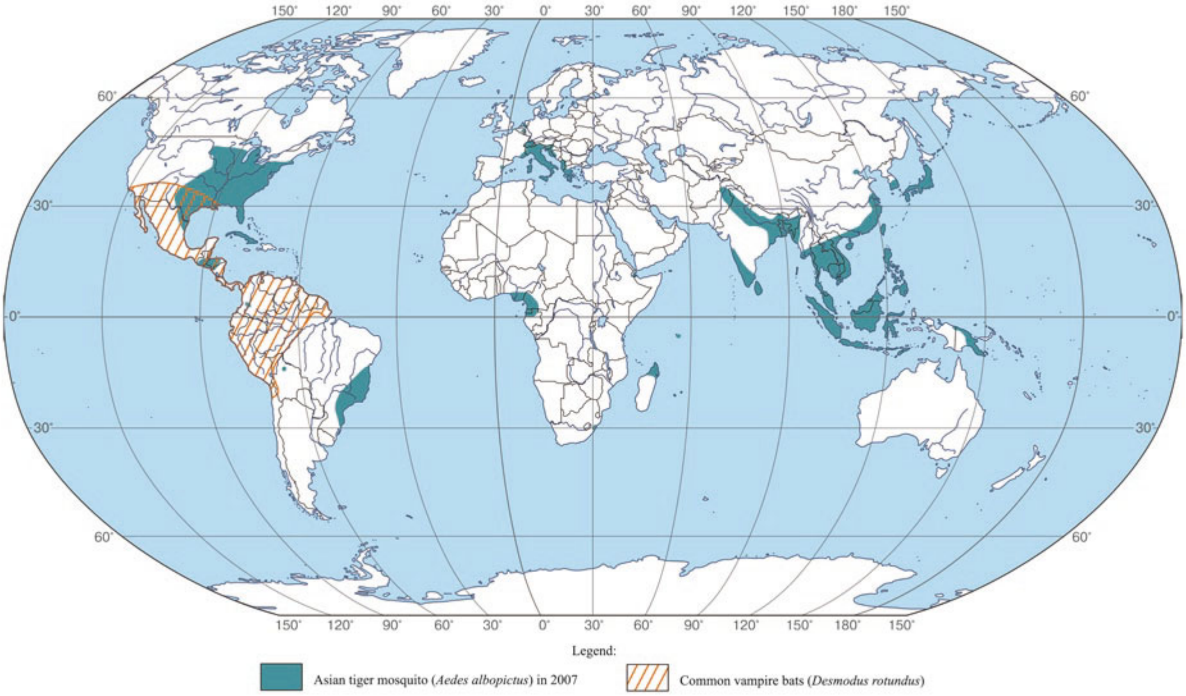

Fig. 5.14 Global distribution of some blood-sucking insects and animals (http://www.thewildones.org./Animals/vampire.html; http://en.wikipedia.org/wiki/Asian_tiger_mosquito)

Photo 5.38 Among the most numerous bloodsucking insects are mosquitoes, numbering about 10,000 species. In general, they dominate in the Arctic prairie (tundra) zone; their total numbers are very high there, while the number of species is not. The picture was taken in the lower part of the Indigirka River (north-eastern Yakutia, Russia) (Photo credit: S.M. Govorushko (Pacific Geographical Institute, Vladivostok, Russia), July 1975)

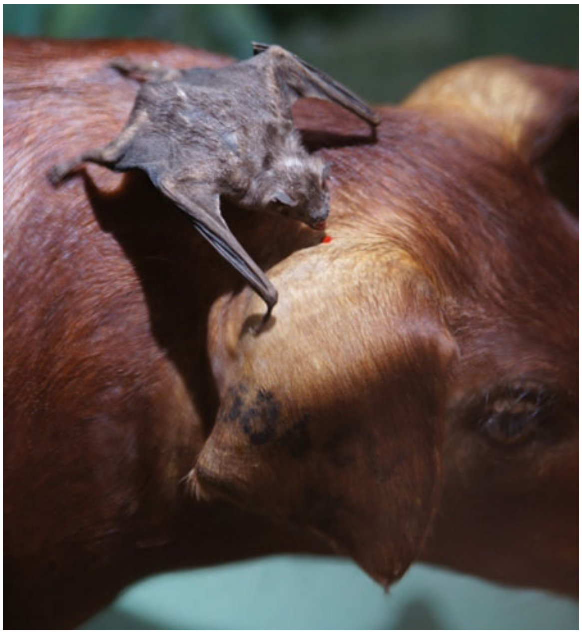

Photo 5.39 Impacts of common vampire bats (*Desmodus rotundus)* on livestock are similar to the effects of attacks by other bloodsuckers: disturbance, weight loss, reduced productivity, etc. The photo shows a common vampire bat feeding on a cow (Photo credit: http://en.wikipedia.org/wiki/Common_Vampire_Bat)

Photo 5.40 The little vampire catfish candiru (*Vandellia cirrhosa*) is another bloodsucking animal; it inhabits rivers in South America. This is the only vertebrate that parasitizes humans. Candiru bites through human skin and sucks the blood of the victim once it reaches its prey. A case of a candiru entering a human orifice has been documented. In this instance, the victim had a candiru swim into his urethra as he urinated while thigh-deep in a river. The victim underwent a 2 h urological surgery to remove the candiru (Photo credit: Dr. Peter Henderson, PISCES Conservation Ltd)

The bedbugs from the family *Cimicidae* have the most medical-veterinary importance of all bloodsucking *bedbugs* (Great medicinal encyclopaedia, vol 10 1979). They usually live in human habitations and feed on human blood. With their mass reproduction, these bugs cause people concern, depriving people of their normal sleep and rest. Long-term and massive bedbug attacks lead to a reduction of haemoglobin in human blood (Insects and ticks of the Far East 1987).

From a *veterinary point of view*, bedbugs are most important for *poultry* and *rabbit breeding*. Animals and birds are disturbed, comb itching areas of their body, and they lose weight. Chickens reduce their egg production. Chicks 1–6 days old suffer the most. They sit hunched over with half-closed eyes and drooping wings under massive bedbug attack. Rabbits develop dermatitis as a result of combing (Parasitology and invasive diseases of livestock animals 1975).

The most important bloodsucking *mites* are hard ticks (family Ixodidae), soft ticks (family Argasidae) and gamasid mites (subfamily Gamasoidea) (Insects and ticks of the Far East 1987). They are characterized by sucking vast amounts of blood, which can sometimes weigh several 100 times more than the weight of the hungry specimen itself. For example, the linear dimensions of ticks increase (by the end of suction) by more than ten times, and they increase in volume up to 300 times (Tarasov 1996).

The impacts of ticks on *animals* and *humans* can be divided into *three types*: (1) *mechanical* damage to skin integrity, (2) saliva *toxic* effects and (3) blood *withdrawal*. All of these effects can cause anaemia, local inflammation, itching and other effects, resulting in deterioration of the body. Some types of gamasid mites cause significant damage to the poultry industry. Thus, mass attack by the red mite *Dermanyssus gallinae* greatly weakens chickens, reduces their egg production, and can even cause death (Insects and ticks of the Far East 1987).

Leeches are among the best-known bloodsucking *animals*. They are widespread mainly in tropical and subtropical zones. They are dangerous not only for external blood suction; they sometimes cling to the wall of the trachea or glottis in case of ingestion by drinking. Leeches grow in size with blood ingestion and can close the lumen of the trachea, causing death by suffocation (Great medicinal encyclopaedia, vol 6 1977).

Terrestrial leeches attack humans and warm-blooded animals when they walk on wet grass, in wetlands, and in other wet areas. Leeches that live on the islands of Java, Sumatra and Kalimantan are very dangerous. They hide in trees and attach to animals and humans that pass under them (Shteinmann 1984).

Several species of *bats* are bloodsucking animals that live in South and Central America. They suck blood for approximately 30 min, sometimes an hour or more. Vampire bats absorb 15–50 ml of blood during every night feeding (Medical theriology 1989).

In general, the impacts of common *vampire bats* (*Desmodus rotundus*) on livestock are similar to the effects of attacks by other bloodsuckers: disturbance, weight loss, reduced productivity, etc. Vampire bats attack humans only when they can not find suitable animal prey. In Peru, vampire bats bit 1,101 people in 2004.

The little vampire catfish *Candiru* (*Vandellia cirrhosa)* is another bloodsucking animal; it inhabits rivers in South America. This is the only vertebrate that parasitizes humans. Candiru bites through human skin and sucks the blood of the victim once it reaches its prey. Candiru can swim up the urinary tracts of people. Several cases of death due to blood loss are reliably known (Ricciuti 1979).

The influences of bloodsucking insects, mites and animals on human activities are illustrated by Photos 5.38–5.40.

5.7 Predatory Animals

Predatory animals are animals that kill and devour other animals. Predation is a universal way of hunting for food and feeding; it is characteristic of all types of animals. Predators usually have well-developed nervous systems and sensory organs. These help them to find and recognize their prey. They are also well provided with means to capture, overwhelm, kill, eat and digest their victim.

Predators either *ambush* (lie in wait) or *pursue* (follow through) their prey. *Collective hunting* sometimes takes place (Biological encyclopaedic dictionary 1986). Regarding human activities, the most important are predatory fish, reptiles, mammals and birds. They are described in Sects. 5.7.1–5.7.2.

5.7.1 Fish and Reptiles

Sharks, barracudas, some eels, and piranha are the only dangerous fish to humans among numerous predatory fish. Areas of highest shark attack risks are displayed in Fig. 5.15.

There are approximately 30–40 *dangerous shark species* out of a total of 500 known sharks. The great majority of deadly shark attacks are attributed to four species: Great White Shark (*Carcharodon carcharias*), Bull Shark (*Carcharhinus leucas*), Tiger Shark (*Galeocerdo cuvier*), and Oceanic Whitetip Shark (*Carcharhinus longimanus*) (Last and Stevens 2009).

The most dangerous freshwater shark is the grey bull shark (also known as the *Zambezi shark*, *Carcharhinus leucas*). The *Ganges shark* (*Glyphis gangeticus)*, which dwells in the Ganges River of India, and its tributary, the Hooghly, is also dangerous (Dossier 1985).

Regarding the *scale of danger to humans*, an average of 98 people per year were attacked by sharks in the period between 1990 and 2006 whilst approximately 6 per year were fatal (Last and Stevens 2009). In times of the *slave trade* and *wars*, the death toll *was higher*. Slave-merchant skippers threw their slaves overboard when their ships were approached by the British navy. Damage to ships and airplanes in battles sent numerous people overboard, many of them wounded, in shark-infested waters.

The *most famous cases* of such events include the attack on 28 November 1942 on the troopship *Nova Scotia*, which was torpedoed near Delagoa Bay, south-eastern Africa (approximately 1,000 people died); the destruction of the transport ship *Cape San Juan*, which was torpedoed by a Japanese submarine in the Pacific Ocean (448 persons died out of 1,429); the destruction of the cruiser *Indianapolis* on 30 July 1945, which was sunk by a Japanese submarine in Philippine waters (883 people died out of 1,196) and the destruction of a British military ship torpedoed in the southern Atlantic (280 people died and 170 survived).

Obviously *not all of the people killed* became victims of sharks, but their numbers are important. The next morning, rescuers at the scene of the *Nova Scotia* sinking (the ship was torpedoed at night) found many bodies in life jackets. All of them were legless. Many survivors

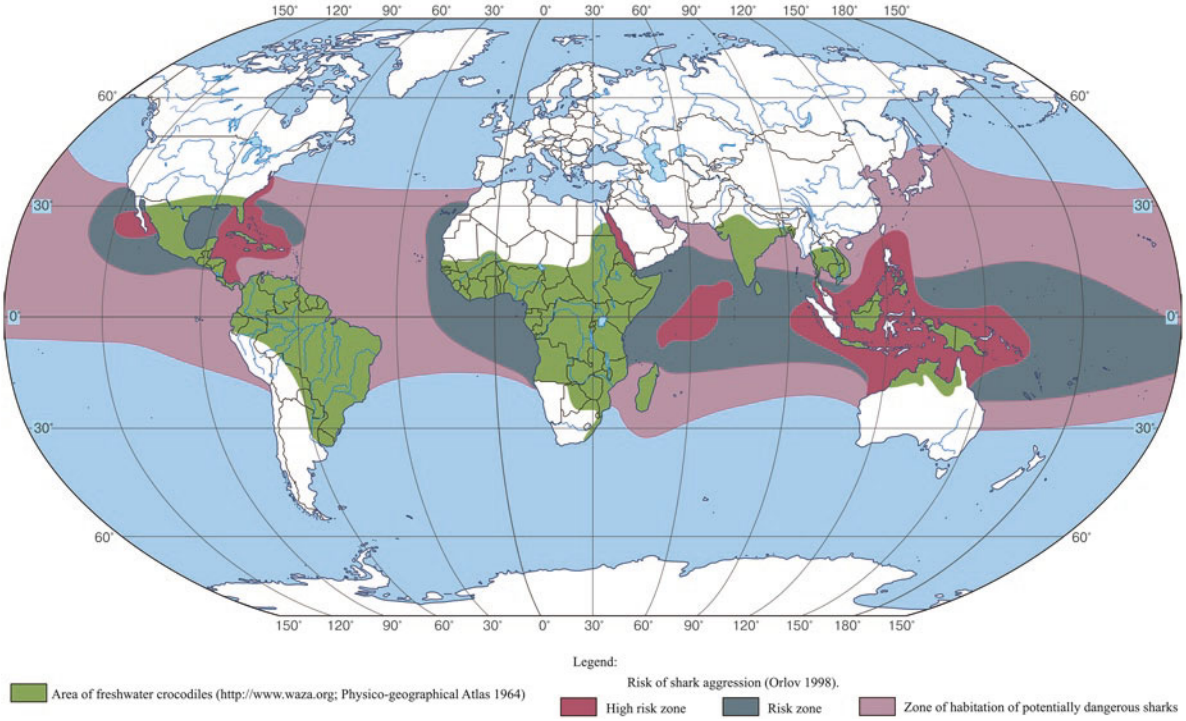

Fig. 5.15 Distribution of some aquatic predatory animals

had bite marks, and 88 corpses were mutilated by sharks (McCormick et al. 1992). According to different sources, 50–80% of shark attacks on humans end in *death.* If the victim of such an attack is not eaten alive, he or she dies from loss of blood or shock (Halstead 1970).

Barracudas inhabit tropical and subtropical waters. The most dangerous one is the great barracuda, which reaches 1.8 m in length and 45 kg in weight. Several cases are known of *human deaths* due to attacks by great barracudas (Ricciuti 1979; Dossier 1985).

Most recorded barracuda *attacks* on people (approximately 40) are believed to have occurred when the barracuda mistook swimsuits or swimming gear for the small fish they usually consume. The real danger of barracuda attacks on people is loss of blood or weakening; people can die or be drowned (Ricciuti 1979).

Two species of *eel* represent danger for humans also: the moray eel (*Muraena*) and the conger eel (*Conger*). They both are bottom-dwelling fish that inhabit crevices, caves and grots in rocks. There are known cases when reckless scuba-divers provoked morays by chasing them or putting their hands and feet in eel's hideouts (Orlov 1998).

Piranha are freshwater fish, 25–60 cm long, which live in the Amazon and Orinoco River basins in the north-east part of South America. Four species of black piranha are dangerous to people. There are *numerous cases* of known piranha attacks on humans, but very few fatalities have been recorded (Dossier 1985).

Another freshwater fish that has impacts on human activities is the European *catfish*. They reach 4.5–5.0 m in length and masses of 300–320 kg, and they are present in the Danube and Amu Darya Rivers, in Turkish and Eastern European regions (Pigulevsky 1964; Ricciuti 1979). Accounts of the deaths of small *domestic animals* (geese, ducks, dogs, sheep, etc.) are quite numerous.

Among *reptiles,* crocodiles are the most dangerous. Crocodiles are divided into *three families*: (1) alligators, (2) crocodiles and (3) gharials. The most abundant is the *crocodile* family. They include 3 genuses and 15 species, 13 of which are dangerous to people. The most *significant* to human activities are *two species*: (1) Nile crocodile (*Crocodylus niloticus*) and (2) estuarine crocodile (*Crocodylus porosus*). The habitat areas of freshwater crocodiles are shown in Fig. 5.15.

Photo 5.41 Piranhas (family Serrasalmidae) are carnivorous fish of South America that can attack humans, but such accidents are rare. The photo shows the head of a piranha with its sharp teeth.Photo credit: Vidad Haddad Jr. (Boticatu School of Medicine, São Paulo State, Brazil)

Photo 5.42 Not infrequently, piranhas cause lacerations in fishermen in the rivers of South America. The photo shows the bite of a piranha in the hand of a freshwater fisherman who was injured when he was taking the fish off a hook (Photo credit: Vidal Haddad Jr. (Boticatu School of Medicine, São Paulo State, Brazil))

Presumably, hundreds of people have found death from *Nile* crocodiles' teeth, but it is hard to prove the numbers. They cause significant damage to *grassland farming*. *Estuarine crocodiles* live in southern India, Sri Lanka, New Guinea, Sunda Isles, Philippine islands, northern Australia and some Pacific islands. Unlike other crocodiles, this species has adapted to inhabit seawater and is capable of swimming on high *seas.* They have been repeatedly observed a 1,000 km away from the nearest beaches (Naumov et al. 1985).

Data indicate that 2,000 people become victims of estuarine crocodiles in *India* every year (Polenov 2008). The total worldwide death toll is several thousand people (Newman 1989). The most tragic incident took place on *Ramree Island* near *Burma* in January and February of 1945. It was part of the Indian 15th Corps 1944/45 offensive on the Southern Front of the Burma Campaign during World War II. There, Allied troops attacked Japanese infantry and pushed them into mangrove swamps infested with crocodiles. Approximately, 20 out of 1,000 of them were alive the

Photo 5.43 Among reptiles, crocodiles are the most dangerous to humans. They cause significant damage to grassland farming also. The photo shows a saltwater crocodile in the Adelaide River, Northern Territory, Australia. It is 6 m long (Photo credit: J.P. Fischer, 19 June 2002)

next morning (http://en.wikipedia.org/wiki/Battle_of_Ramree_Island). Fifty-eight attacks by estuarine crocodiles on people were recorded in *Australia* from 1870 to 1995; 27 of them were deadly (Williamson et al. 1996).

Another predatory reptile that is dangerous to humans is the American alligator (*Alligator missisipensis*). It inhabits six southern states in the United States: Florida, Alabama, Georgia, Lousiana, South Carolina and Texas. There were 236 alligator attacks on people recorded in the United States during 1948–1995; eight of them were *fatal*. Ninety-two percent of all attacks (218 out of 236) and seven out of eight fatalities took place in Florida (Conover and Dubow 1997).

The impacts of predatory fish and reptiles on human activities are illustrated by Photos 5.41–5.43.

5.7.2 Mammals and Birds

The wolf, tiger, bear, leopard (panther), lion, jaguar, lynx, cougar, coyote, fox, hyena, jackal and ferret are *dangerous predators* to humans and domestic animals. The distributions of some predatory mammals are shown in Fig. 5.16. *Predatory birds* include eagles, hawks, vultures, falcons and crows.

The greatest numbers of *wolves* in the early 1980s were present in Canada (over 28,000), Alaska (10,000–15,000), Mongolia (10,000) and the former Soviet Union (7,000) (Medical theriology 1989). Mortality was very substantial due to their predation in the past. For example, wolves killed 624 people in Uttar-Pradesh (India) in 1878 (Rajpurohit 1999). They killed 205 people in Vjatka province (Russia) during 1896–1897 (Pavlov 1990). In our time, this problem is most serious in India. For example, wolves killed 60 children and injured another 20 in the state of Bihar from April 1993 to April 1995 (Rajpurohit 1999).

Tiger (*Panthera tigris*) attacks can be categorized into three *groups*: (1) attacks by man-eating tigers, (2) protective counterattacks by hunted tigers on hunters and (3) collateral attacks on people as they try to protect livestock, or simply unexpected encounters.

There are three or four *man-eating* tigers out of every thousand (Gee 1968). It is reliably known that, at least, a few 'serial killer' tigers exist in India. In 1862, one such predator interrupted the construction of the Bombay–Allahabad railroad, killing over 100 workers before the tiger itself was eliminated (Shishkin 1972). Some time later in Madhya Pradesh, a tigress was eliminated that had killed 287 people (Anderson 1964). There was a raging tigress in Kumaon in the 1920s that claimed 434 victims (Horrors of nature 1997).

In some regions, mortality was very *noticeable*. Tigers killed 4,200 people in the southern part of Bengal alone (low-lying Ganges–Brahmaputra River delta) in 1860–1866. Tigers killed 8,600 people in India in 1877–1886, and these predators killed 275 people in the coastal part of Bengal during 1961–1970 (Shishkin 1972).

Bears also contribute to the deaths and injuries of people. India is the champion here also. Sloth-bears (*Melursus ursinus*) killed 48 people and injured 687 people in Madhya Pradesh in attacks during the period from April 1989 to March 1994. Black American bears (*Ursus americanus*) traumatized 1,927 people in Yellowstone National Park (United States) from 1930

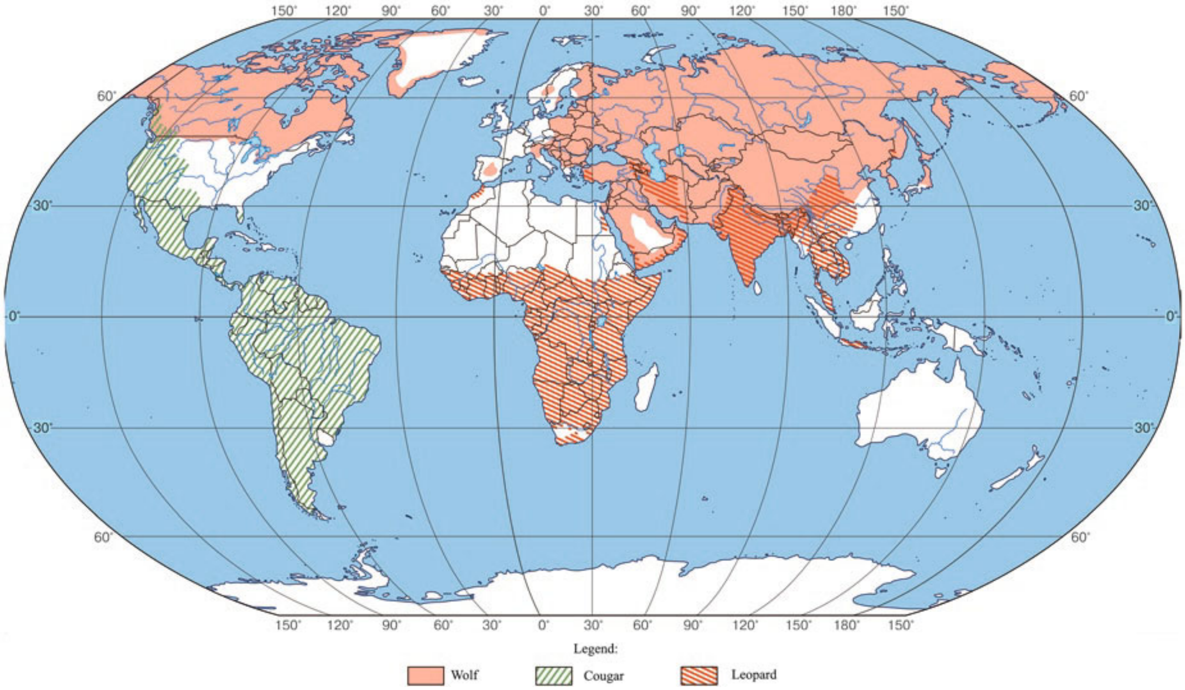

Fig. 5.16 Distribution of some predatory mammals (Adapted from http://www.waza.org; http://wolf-web.tieranet.com)

Photo 5.44 Of all the carnivorous animals in the United States, coyotes (*Canis latrans*) cause the most damage to livestock. For example, in 2005, they killed 137,000 sheep. Of the 190,000 head of cattle killed by all predators, coyotes accounted for 97,000. A coyote with a typical throat hold on a domestic lamb is shown (Photo credit: US Department of Agriculture, January 2008)

to 1978, and grizzly bears (*Ursus arctos horribilis*) injured 75 people. Approximately, 100 people were killed by grizzly bears overall in North America over the past 100 years (Rajpurohit and Krausman 2000).

There are several cases of mass *leopard attacks* (*Panthera pardus*) on humans recorded in history. One of these animals killed approximately 200 people in India in 3 years in the late 1850s (Heptner and Sludsky 1972). There was the widely known *Rudraprayag maneater*, which killed 125 people during 1918–1925 (Corbett 1991). Another Indian leopard killed over 400 people in 77 mountain villages, until it was shot dead

Photo 5.45 There are several recorded cases of mass leopard (*Panthera pardus*) attacks on humans. The photo shows British hunter Jim Corbett after killing the man-eating Leopard of Rudraprayag (male man-eating leopard, claimed to have killed over 125 people) in 1925 (Photo credit: http://en.wikipedia.org/wiki/Jim_Corbett_(hunter))

(Wild cats 1981). According to official statistics, leopards killed 194–300 people annually in India during 1876–1886. The *total number of deaths* amounted to 2,368 people. Cases of man-eating leopards were also found in Africa (Horrors of nature 1997).

Lions (*Panthera leo*) inhabit central Africa mainly. There were two world-famous lions that carried off and ate at least 28 people who were working on construction of the Mombasa-Nairobi railroad (Kenya) in 1898. They went down in history as the 'Tsavo lions'; they were named after the river over which a bridge was then built (Wild cats 1981).

Sporadic deaths are known due to attacks by cougars (*Felis concolour*), hyenas (*Hyaenidae*), jaguars (*Panthera onca*) and coyotes (*Canis latrans*).

The impact of predators on *livestock* is significant. Harm caused by *wolves* is well known. One pack of wolves carried off up to 200 goats and 300 pigs from villages located in their habitat (an area of 50 km^2) in the Mahuadanr Valley (Bihar, India) annually (Rajpurohit 1999). Wolves killed 864,995 head of livestock – sheep, 52%; cattle, 18.1%; horses, 16%; pigs, 7.2%; goats, 5.8% and others, 0.9% – in the USSR during the period from April 1924 to March 1925 (Pavlov 1990). They killed 14,000 sheep, 3,000 cows and 1000 horses in 1977 (Wolf 1985).

Tigers have a significant impact on livestock. For example, they killed approximately 30,000 head of livestock in India in 1890 (Shishkin 1972). *Bears* cause some damage to livestock. There is a case when a bear in the state of Colorado (United States) attacked 800 head of cattle at the beginning of the nineteenth century (Horrors of nature 1997).

Predatory mammals cause some damage to *hunting*. They do so in the following *ways*: (1) eat and damage hunting trophies, (2) damage traps and (3) eat bait. For example, wolves destroyed about 600 foxes in the traps of hunters in Taimyr, Russia, in the 1974–1975 hunting season (Pavlov 1990).

Birds of prey are often detrimental to livestock farming, especially to owners who are farming different kinds of animals (mink, nutria, fox, etc.). Their impact can be *direct* (injured calves) and *indirect* (eating food intended for a brood).

Fish-eating birds damage *fisheries* due to their feeding activities. In Western Europe, cormorants, grey herons, red-breasted merganser and seagulls cause serious damage to *pond farms* where carp and trout are

Photo 5.46 Birds of prey are often detrimental to livestock farming, especially to owners who are farming different kinds of animals (mink, nutria, fox, etc.). However, the hand-reared birds used for hunting provide benefits to people. The photo shows a Kyrgyz hunter with his golden eagle, in front of a traditional felt (yurt) in Karakol, Kyrgyzstan, in July 2002 (Photo credit: http://en.wikipedia.org/wiki/Falconry)

raised. For example, a single trout farm in Germany has an average damage per season of 35,000 deutsche marks (Oberle 1997). Losses at carp farms from piscivorous birds are 950 kg of fingerlings per hectare, which amounts to a total of 40,000 ton throughout Germany (Geldhauser 1997).

Economic damage from carnivorous mammals to livestock is well documented by US statistics. Predators killed 106,000 head of cattle, worth US$43 million, in 1991. Also, they killed 490,000 sheep and lambs and 83,000 goats; economic losses amounted to US$24 million and US$6.6 million, respectively, in the United States in 1990. The calculated value of livestock losses and poultry losses totalled US$160 million in 1989 (Conover et al. 1995).

The impacts of predatory mammals and birds on human activities are illustrated by Photos 5.44–5.46.

5.8 Venomous and Poisonous Animals and Insects

First, the terms *venomous* and *poisonous* should be clearly understood. Venom is generally injected into its victim either by a sting or bite, while poison is usually ingested or inhaled. Many kinds of animals, including mammals, reptiles, spiders and insects, use venom for hunting and also self-defence.

Animals are clearly divided into *two groups*: (1) venomous, and (2) poisonous. The *first category* includes animals that produce their venom in specific glands or have it as a metabolic product. The toxicity of these animals is *characteristic of the species. Poisonous* animals have exogenous toxins that accumulate in their bodies, and they are toxic only when ingested. Examples of such animals include molluscs and fish that accumulate toxins of blue-green algae in their bodies and insects that feed on toxic plants (Orlov et al. 1990).

Venomous animals are subdivided into actively and passively venomous species, depending on the way they produce their venom. *Actively venomous* animals have designated venom mechanisms and are '*armed'*. Venomous armour of such animals usually includes a venom gland, excretory ducts and wound-inflicting instruments (e.g. reptile teeth, insect stingers and spines of fish).

Unarmed venomous animals are another group of actively venomous animals. These organisms do not possess wound-inflicting devices. Examples include insects with anal glands, holothurians with specialized cuvierian tubules (peculiar organs) and amphibians with skin glands. Such glands produce toxic effects on direct contact with victim integuments. The effect is stronger if toxin suction takes place on the integuments, especially those producing mucus.

Passively venomous animals produce their venom via metabolic processes and accumulate them in organs (such as digestive or reproductive). This mode is characteristic of many fish, molluscs, tailed amphibians and insects.

Infliction occurs in different *ways*: (1) bites (snakes, lizards, spiders, millipedes, ants, caterpillars, etc.), (2) stings (scorpions, wasps, bees and hornets), (3) burns (jellyfish, sponges and actiniae), (4) piercing (fish and echinoderms) and (5) tearing with spurs (duck-bill platypus) (Langley 1999).

There are 5,000 known venomous animal species in the world (Biological encyclopaedic dictionary 1986). It is believed that ten million people suffer injuries from venomous animals every year (Great medicinal encyclopaedia, vol 28 1986).

Levels of toxicity might differ for the same species depending on location, feeding conditions, season and other factors. Females are usually more venomous, and in some species, only females are toxic. There are some individual differences in the levels of toxicity (Great medicinal encyclopaedia, vol 28 1986).

The *sensitivity* of different animals to the *same venom* might also be significantly different. For instance, the same portion of rattlesnake (*Crotalinae*) venom can kill 24 dogs, 60 horses, 600 rabbits, 800 rats, 2,000 guinea pigs, or 300,000 pigeons (Voronov 1981). There are differences in *sensitivity* of species to the *venom of different animals.* Pigs are less sensitive to rattlesnake poison, hedgehogs are resistant to vipers' venom and rodents are insensitive to scorpion venom. Some birds (ravens, storks, condors, secretary birds) eat venomous snakes, chickens eat black widows and black widows themselves eat Spanish flies (Biological encyclopaedic dictionary 1986).

The major categories of venomous animals are considered below.

5.8.1 Venomous Aquatic Animals

The most active *venomous aquatic animals* inhabit seas and oceans, mainly in the coastal zones of tropical seas. Such animals are found in the following taxa: sponges, coelenterates, annelid worms, echinoderms, molluscs, fish and reptiles. The total number of actively venomous marine organisms is approximately 1,200; the number of people affected by their bites and stings is roughly 1.5 million annually (Russell 1984). The numbers of deaths without secondary infections and deaths from sea snakebites do not exceed 75 people per year (Russell and Nagabhushanam 1996). The distributions of some marine venomous and poisonous animals are shown in Fig. 5.17.

Actively venomous aquatic animals may be divided into two *groups* (Stenko et al. 1984) based on their method of inflicting venom: (1) stabbing (armed with thorns, spines and other wounding devices) and (2) stinging (armed with stinging cells containing poisonous substances). The following organisms are considered to be the most significant in terms of their impacts on human activities.

5.8.1.1 Sponges and Cnidarians

Sponges are the lowest multicellular animals that live virtually in all seas and at all depths – from shallow to almost 9,000 m. There are approximately 8,000 described species of sponges in modern fauna, and since many sponges are small, encrusting species, it is suggested that there may be at least twice this number. The vast majority of the species are inhabitants of warm seas, where they are found in habitats ranging from the intertidal zone to depths of up to 6,000 m (http://www.fauna-toxin.ru/11.html). Only a few species represent risk to humans, causing skin irritation and dermatitis. The Caribbean sponge (*Tedania ignis*) secretes large quantities of mucus, which can cause a severe rash. Curious divers suffer the most – they touch sponges with bare hands. In addition, fishermen sometimes pick sponges from their nets.

There are about 9,000 species of cnidarians (jellyfish, sea anemones, etc.); approximately 70 of them are dangerous to humans (Ricciuti 1979). Cnidarians can be divided into two *groups* based on their lifestyle: (1) attached and (2) floating.

Attached cnidarians are dangerous when people touch them out of curiosity or just negligence. A typical example is the hydrocoral *Millepora* (class Hydrozoa), or best-known as fire coral. *Millepora* species can be found in the Indian, Pacific and Atlantic Oceans. They can cause severe pain and burning when touched.

Floating cnidarians pose the worst danger to humans. Dangerous species are found in such taxa as Hydrozoa, Scyphozoa and Siphonophorae.

Of the *hydrozoans*, a small clinging jellyfish with a diameter of just 2.5 cm (*Gonionemus vertens*) can inflict a severe burning sensation on the skin, usually accompanied by rapid blistering, local oedema, general weakness, numbness, joint pains, etc. Several species of the genus *Olindias*, in particular, the well-known flower hat jelly (*Olindias formosa*), can also inflict a painful sting. Clinging jellyfish are widespread but toxic only in a few bays and inlets in *Peter the Great Gulf* (Primorsky Krai, Russia). They are dangerous only in July through August and are most abundant in dry and hot summer seasons (Yakovlev and Vaskovsky 1993).

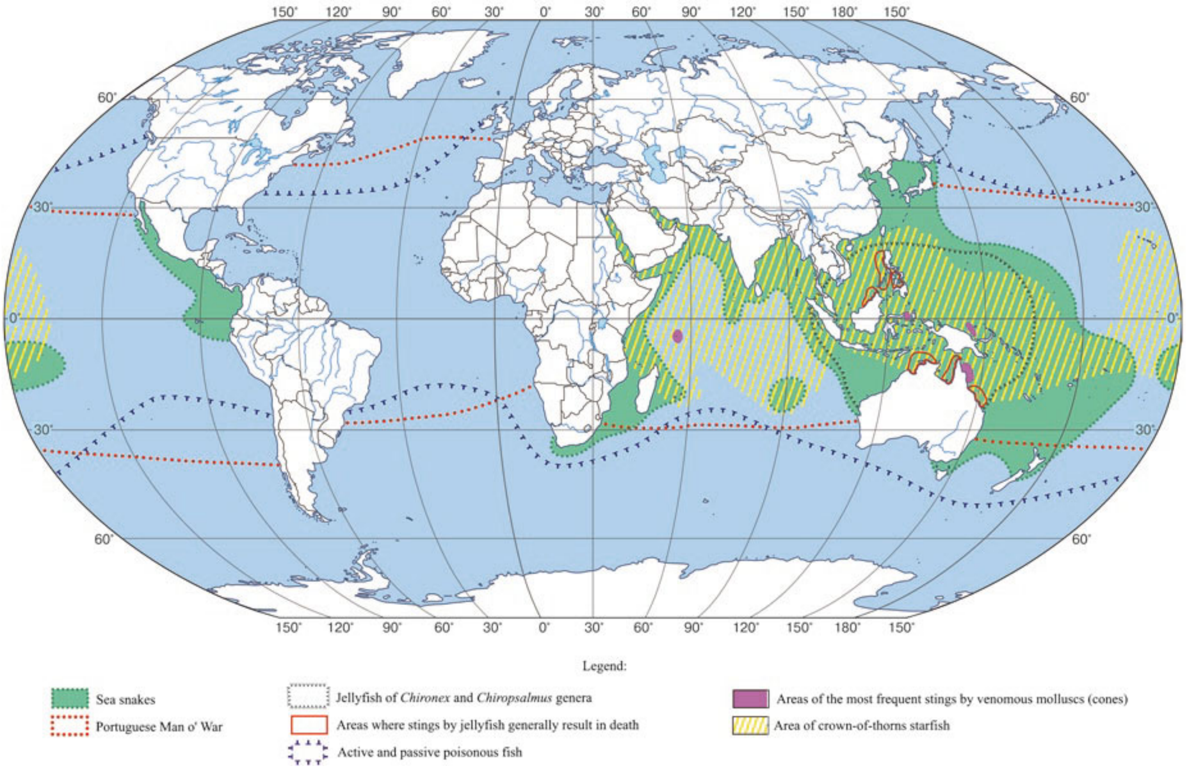

Fig. 5.17 Distribution of venomous and poisonous marine animals (Adapted from Atlas of oceans 1974; http://animals.nationalgeographic.com/animals/invertebrates/portuguese-man-of-war/; http://en.wikipedia.org/wiki/Chironex_fleckeri; http://snake.software.informer.com/wiki/)

In some years, *clinging jellyfish* attacks are widespread. For example, they hit over a 1,000 people in the Amur Bay recreational area on 17 June 1966 alone (Mikulich and Naumov 1974). Touching clinging jellyfish causes three main symptoms: (1) breathing difficulty, 44% of patients; (2) pain, 37%; and (3) mixed reactions, 19% (Migas and Popova 1988).

Jellyfish of the genus *Olindias* live in the subtropics in the Atlantic Ocean, in waters of Southeast Asia and northern Australia and in the Indian Ocean. They have the highest concentrations in shallow shoreline water, which makes them dangerous to bathing children. They stung 500–1,000 people each bathing season near the resort town of Monte Hermoso, Argentina (Williamson et al. 1996).

Scyphozoa jellyfish are large and clearly visible under water. Species that are dangerous to humans belong to the *following taxa*: (1) disc-shaped large jellyfish (order Semaeostomeae), which have four long oral arms; (2) rhizostomae jellyfish (Rhizostomeae), which do not have tentacles or other structures at the bell's edges; (3) crown jellyfish (Coronatae), which have a characteristic deep groove around their umbrellas; and (4) box jellyfish (Cubozoa), which, as their name implies, are cube-shaped medusa.

Dangerous species among the disc-shaped jellyfish include the following: (1) the *stinging sea nettle* (*Chrysaora quinquecirrha*) (dome diameter is 2–20 cm; tentacles are up to 250 cm long; contact with it can lead to severe pain, dermatitis, skin necrosis and muscle cramps), (2) the *lion's mane jellyfish* (*Cyanea capillata*) (the largest jellyfish in the world; diameter is up to 2.3 m and tentacles are up to 36 m long; contact with its tentacles cause immediate burning pain, later accompanied by oedema and skin necrosis), and (3) the *mauve stinger* or purple-striped jelly (*Pelagia noctiluca*) (has a diameter up to 10 cm; contact leads to pain and numbness in affected areas of skin; it is generally not fatal).

In some years, there have been *mauve stinger outbreaks*. For example, in 1977–1979 in the northern Adriatic Sea, the concentration of these jellyfish was so large that they obstructed navigation and inflicted

Photo 5.47 The hydrocoral *Millepora*, or fire coral, is dangerous when people touch it out of curiosity or just negligence; it causes severe pain and burning when touched. The photo shows *Millepora* spp. photographed in the Red Sea in May 2003 (Photo credit: http://en.wikipedia.org/wiki/File:Millepora_fire_coral.JPG)

Photo 5.48 The Portuguese Man of War (*Physalia physalis*) is a floating hydrozoan. The photo shows a typical accident caused by a Portuguese Man of War to a young bather in south-eastern Brazil. The marks of long tentacles are indicative of contact with them. There were mild systemic manifestations (malaise, nausea, vomiting and fever) that persisted for about 4 h (Photo credit: Vidal Haddad Jr. (Boticatu School of Medicine, São Paulo State, Brazil))

Photo 5.49 Clinging jellyfish (*Gonionemus vertens* Agassiz) are widespread but toxic only in a few bays and inlets in Peter the Great Bay (Primorsky Krai, Russia). They are dangerous only in July through August and are most abundant in dry and hot summer seasons. The photo shows consequences of contact with a clinging jellyfish (Photo credit: Yu. Yakovlev, Institute of Marine Biology, Vladivostok, Russia)

great damage to fisheries. In 1978, 250,000 cases were recorded of people struck by purple-striped jellies (Russell and Nagabhushanam 1996). In an *unprecedented event* on 21 November 2007, an enormous 10 square mile (26 km^2) swarm of billions of these jellyfish wiped out 100,000 fish on a salmon farm in Northern Ireland, causing around £1 million damages (http://en. wikipedia.org/wiki/Pelagia_noctiluca).

Stomolophus is the most dangerous Rhizostomeae jellyfish representative; they live in moderately warm waters of Japan, Korea and China. The largest specimens reach 200 kg in weight, with tentacles up to 2 m long. Usually, they affect hands and feet of swimmers and fishermen, causing deep wounds and blisters. Acute pain is experienced, along with nausea, fever, heavy sweating and respiratory failure. In the summers of 1984, 1986, 1987 and 1988, approximately *3,000 people* were *stung* at Beidaihe beaches (a coastal city of Bohai in *China*) by the very large *Stomolophus nomurai*. Lethal cases numbered 8 people at the time (Williamson et al. 1996).

Linuche (class Scyphozoa, order Coronatae) is the most dangerous representative of the crown *jellyfish order*; it is common in the tropical Atlantic and Pacific Oceans. *Linuche* creates huge problems in the Caribbean Sea, where large concentrations congregate (bloom) and perturb both tourists and fishermen. Contact with its tentacles leads to the formation of deep wounds with blisters and numerous rashes on the skin, which can last for over a year (Orlov 1998).

The *box jellyfish,* order Cubozoa, incorporates many species deadly to humans. The venom of cubozoans is distinct from that of scyphozoans. One of the most famous cubozoans is the lethally venomous *box jellyfish* (*Chironex fleckeri*), which lives in tropical waters of the Atlantic, Pacific and Indian Oceans. The height of its dome is 22 cm, and each of its 60 tentacles can reach several metres in length. Medium-sized tentacles contain four billion striking cells charged with highly toxic venom. The amount of venom in one *C. fleckeri* is enough to kill 60 adult humans. This jellyfish is noted to be the fastest jellyfish in the world. With frequent flexes of its dome, it can move at speeds up to 10 km/h (Orlov 1998).

Deaths from box jellyfish stings are due to cardiac arrest, caused by cardiotoxins in the venom. Numerous cases of deaths from burns caused by *C. fleckeri* are described in a book by E.R. Ricciuti (1979). Mortality from this jellyfish is the highest on the northern coast of Australia. Over 70 people were killed by contact with *Chironex fleckeri* alone in waters around Queensland during 1900–1985 (Marsh and Slack-Smith 1986).

There are several other dangerous species of box jellyfish that are similar to *Chironex fleckeri* in appearance and have similar toxic venom. These include *Chiropsalmus*, *Chiropsoides* and *Chirodropus*. It is believed that *Chiropsalmus* is responsible for 20–50 deaths that occur in the Philippines annually (Fenner 1987). *Chiropsoides* and *Chirodropus* cause severe pain, dermatitis, tissue necrosis and respiratory disorders (Williamson et al. 1996).

Irukandji jellyfish, *Carukia barnesi* (bell 12 by 30 mm in height) and *Malo kingi* are small, yet extremely venomous, and found near Australia. Inflicted victims develop what is known as *Irukandji*

Photo 5.50 Venomous jellyfish greatly complicate recreational activity. In many regions, swimming holes are guarded by protective nets. The photo shows a jellyfish netted enclosure at Ellis Beach, Cairns, Queensland, Australia (Photo credit: Colin Henein, 20 May 2003)

syndrome; symptoms include severe pains, headaches, nausea, sweating, vomiting and increased heart rate and blood pressure, amongst other symptoms. Fatalities have been recorded from envenomation.

Two species of *siphonophores* (*Siphonophorae*) are well recognized as venomous; they belong to the family Physaliidae and are widespread in the Indian and Pacific Oceans. The *Atlantic Portuguese Man of War*, or bluebottle (*Physalia physalis*), is typically found in tropical Atlantic waters. They have an average dome diameter of 18 cm, and their tentacles can reach 9 m in length (Kromi 1971). Swimmers often encounter this species. Touching this jellyfish causes almost instantaneous sharp pain, similar to pain from an electric shock. In some cases, this leads to paralysis and death (Ricciuti 1979). *Physalia utriculus, otherwise known as the Indo-Pacific Man of War*, is found in the Indian and Pacific Oceans. It is a smaller jellyfish and despite inflicting serious pain also, it is not known to be fatal.

The impacts of sponges and cnidarians on human activities are illustrated by Photos 5.47–5.50.

5.8.1.2 Worms, Echinoderms and Molluscs

Of the *segmented worms* (Annelida), the Polychaete family represents the greatest danger to humans. Polychaetes are found everywhere in all oceans; most burrow or build a tube and inhabit niches between rocks, shells and grass. Their toxicity is connected to hollow tubules filled with toxin (either temporarily or permanently), or to salivary organs that produce toxins. Injury from polychaetes is usually job related and, therefore, generally occurs to fishermen. Venom from polychaetes causes local symptoms such as acute pain and swelling and general symptoms such as headache, vomiting and breathing problems (Orlov and Gelashvili 1985). The most dangerous species are *Nereis* (White Sea), *Eunice* (Australian coastal waters) and *Euritoe*, which inhabit the Mediterranean (Orlov 1998).

There are approximately 80 toxic species of *echinoderms* out of an estimated 7,000 that exist today (Ricciuti 1979). Representatives of *three classes* of echinoderms are of concern to humans: (1) starfish, (2) sea urchins and (3) holothurians. The crown-of-thorns starfish (*Acanthaster planci*) is the second largest starfish in the world. Each of their spines is encased in a sheath that contains venom. The injected neurotoxin can cause a stinging pain that can last for hours; other symptoms include nausea and vomiting. Oedema can occur around the punctured skin.

Other starfish potentially capable of envenomation include members of the genus *Echinaster*, which

Photo 5.51 Of the segmented worms (Annelida), the family Polychaetes represents the greatest danger. Their toxicity is connected to hollow hair filled with toxin temporarily or permanently, or with salivary organs that produce toxins. Poisoning by polychaetes causes local symptoms such as acute pain and swelling, and general symptoms such as headache, vomiting and breathing problems. *Alitta succinea*) from de Spuikom, Oostende, Belgium, is shown here (Photo credit: Hans Hillewaert)

Photo 5.52 The marine snail *Conus geographicus* is shown here. Venomous gear of these molluscs include the toxic bulb, passage, radula or lingual ribbon (toothed blade on the tongue surface) and proboscis. Major groups of people who are at risk include (1) professional divers who are stung while collecting molluscs in mesh bags attached to the waist, and (2) inexperienced collectors who are stung while cleaning beautiful shells (Photo credit: Kerry Matz, National Institute of General Medical Services, United States)

possess thorny spines and small pits from which toxins are secreted. *Plectaster* and *Solaster* species are reported to cause contact dermatitis.

Sea urchins (Echinoidea) are capable of causing venomous injuries in humans. They utilize specialized spines or pedicellaria to deliver their venom. There are some 800 sea urchin species (Echinoidea), and only a small percentage are toxic. Sea urchin stings lead to acute pain and oedema, heartbeat disturbances, and paralysis of facial muscles and limbs. There have been many tragic accidents among divers (sponge, pearl, recreational divers, etc.); they pass out and drown after sea urchin injections (Orlov and Gelashvili 1985). Tropical sea urchins are the most dangerous, such as *Toxopneustes pileolus* and *Diadema*, *Tripneustes* and *Echinotrix* species (Orlov 1998).

Holothurians (sea cucumbers) are widespread and number 1,100 species. In some cases when sea cucumbers (*Bohadschia argus*) are disturbed, they extrude Cuvierian tubules that are toxic (contain holothurin) and can be extruded from the anus as a defensive mechanism. Contact with skin causes intense irritation, and if it comes in contact with the eyes, it can cause permanent blindness. The viscera of holothurians have been used since ancient times by people of the South Pacific to poison fish in closed lagoons/inlets.

There are two *classes* of actively poisonous molluscs: (1) gastropods and (2) cephalopods. Eighteen species of gastropods are deadly to humans. All of them are members of the *Conidae* (cone shell) family (Williamson et al. 1996). Cone shells are found throughout the tropics and subtropics in the Indian and Pacific Oceans. The composition of venomous armour of these molluscs includes a muscular bulb, a tubular duct, radula or lingual ribbon (toothed blade on the tongue surface) and a proboscis.

Major *groups of people* who are at risk include (Orlov and Gelashvili 1985) (1) professional divers who collect molluscs in mesh bags attached to their waists and are stung and (2) inexperienced collectors who are stung while cleaning shells. The injection is not very painful in itself and is comparable with a wasp sting. *Symptoms of envenomation* appear when the toxin is absorbed; symptoms include oedema, vision disturbances, shortness of breath, vomiting and dizziness. An injured person might die from respiratory muscle paralysis and heart seizure if he or she does not get medical help. Cone shells are the most dangerous shellfish in Japanese waters; 542 envenomation accidents have been recorded there, with 185 lethal (Russell 1984).

There are few poisonous *octopuses* among the *cephalopods*, and all of them are relatively small. Their salivary glands produce neuromuscular paralysing venom (containing tetrodotoxin). The most dangerous is the *'blue-ringed octopus'* (genus *Hapalochlaena*). They are found in sheltered rock pools and crevices in the Pacific Ocean from Japan to Australia. The mechanism of toxicity from blue-ringed octopus bites is well known: rapid flaccid paralysis caused by the sodium-channel paralytic neurotoxin. Some lethal accidents have been recorded (Ricciuti 1979; Dossier 1985). There are two actively poisonous octopus species in Californian waters and one in the Caribbean (Orlov 1998).

Pfeffer's flamboyant cuttlefish (*Metasepia pfefferi*) is a very small cuttlefish growing to approximately 8 cm in length at full maturity. It has recently been discovered that it also has a deadly venom. Mark Norman, with Museum Victoria in Australia, has shown the toxin to be as lethal as that of its fellow cephalopod, the blue-ringed octopus.

The impacts of worms, echinoderms and molluscs on human activities are illustrated by Photos 5.51 and 5.52.

5.8.1.3 Fish and Reptiles

Fish generally inflict venom via sharp spines attached to toxic glands, or they are coated with venomous mucus. Venomous *chondrostei* (primarily *cartilaginous*) fish include a few dozen species of bat rays, one shark and two chimaeras. There are some 1,200 species of venomous fish *worldwide*. Actively venomous *bony fish* (Osteichthyes) are more numerous and include different species of dragonets (Callionymidae), catfish (order Siluriformes), a number of scorpionfish (Scorpaenidae), stargazers (Uranoscopidae) and toadfish (Batrachoididae, Tetraodontidae and Psychrolutidae).

The *spiny dogfish*/spurdog/mud shark or piked dogfish (*Squalus acanthias*) is pervasive in northern parts of the Atlantic and Pacific Oceans. It has two dorsal fins, each of which has spines that can inflict venomous wounds. The prick causes intense pain, lasting hours. In many cases, swelling takes place. Some lethal cases are known (Halstead 1970).

Out of 30 species of *cartilaginous chimaeras*, only European and Pacific *chimaeras* are harmful to humans. A venomous bony spine is situated in front of the dorsal fin. Chimaeras inflict very painful wounds, but most of them are accidental (Halstead 1970).

Poisonous armour of *bat rays* includes tail fin spines. *Stingray* family representatives are the most harmful and range in size. Some Atlantic species are smaller than 50 cm, while the Australian and New Zealand *Captain Cook stingray* is up to 5 m long and 2 m wide.

The distinctive *features* of the stingray are the long, whiplike tail, with one to four venomous spines 20–40 cm long. Usually, people are wounded when they step on a motionless stingray that is half-submerged in sand. Stingray venom causes respiratory disturbances, spasms, fainting and sometimes paralysis. Every year, 1,500 encounters between people and stingrays occur in the United States (McCormick et al. 1992).

Representatives of the *river-dwelling stingray* family (Potamotrygonidae) inhabit rivers in South America, Indochina and South Africa (Ricciuti 1979). They are also known to be very dangerous. For example, several thousand patients wounded by stingrays are admitted to Colombian hospitals every year. Eight lethal cases were recorded at a small provincial hospital in 5 years, plus 23 leg amputations; 114 patients were disabled for up to 8 months (Williamson et al. 1996).

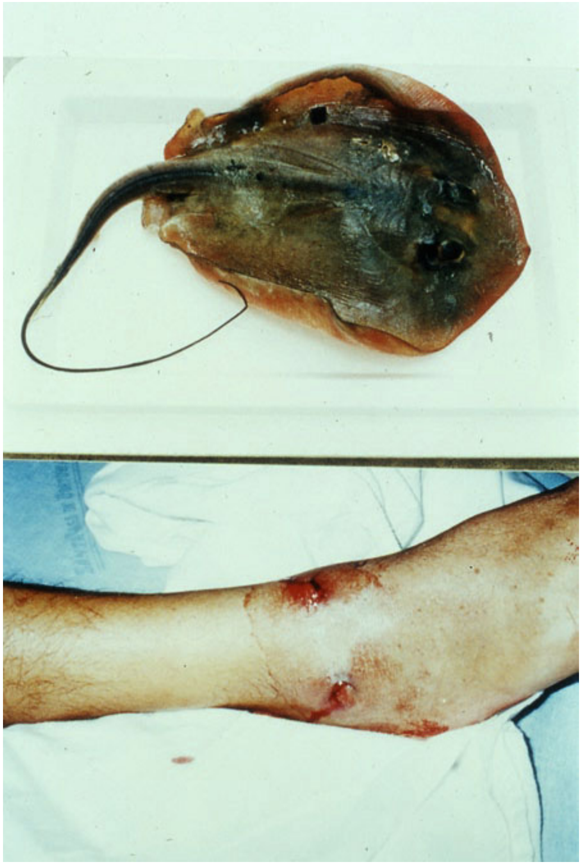

Photo 5.53 *Dasyatis* spp. is the more common genus of stingray in the Atlantic Ocean. The accidents they cause are severe and the trauma very important. The sting has venomous epithelium. The trauma and the pain are very violent. On the Brazilian coast, this kind of injury is common in fishermen and rare in bathers. The photos show a stingray and the wounds it inflicted (Photo credit: Vidal Haddad Jr. (Boticatu School of Medicine, São Paulo State, Brazil))

Photo 5.54 There are several venomous catfish. Their dorsal and pectoral fin barbs are equipped with venom glands. The photo shows an injury caused by a catfish (urutu catfish, *Genidens genidens*) to a bather. Small catfish are discarded by fishermen at beaches and in shallow waters, leading to persons being stung. The injures are caused by the trauma of the stings and venom (Photo credit: Vidal Haddad Jr. (Boticatu School of Medicine, São Paulo State, Brazil))

Dragonets usually injure people who are walking on sandy bars or swimming in shallow water near eastern beaches of the Atlantic and Mediterranean. Other humans at risk include fishermen who pick dragonets from their nets and scuba divers. Venomous amour and medical symptoms caused by dragonets are similar to those of stingrays.

There are several venomous *catfish*. All catfish that belong to the Plotosidae family are venomous (except *Plotsus fisadoha*). The anterior spines of the dorsal and pectoral fins can inflict painful wounds. In *P. lineatus*, the spine of the first dorsal and each of the pectoral fins may even be fatal. Fishermen are their usual victims. The major symptoms are long-lasting intense pain, heavy neoplasm and inflammation. Several lethal cases are known (Halstead 1970).

The *stonefish* (Synanceia) is considered to be the *most venomous* fish. They are found in the coastal regions of Indo-Pacific oceans. They are primarily marine, though some species are known to live in rivers. Its species have potent neurotoxins secreted from glands at the base of their needle-like dorsal fin spines,

Photo 5.55 Sea snakes are from 0.3 m to 2 m long. Most victims are fishermen working with their nets. Reckless scuba divers are a second group at risk. They provoke these snakes to aggression. The most dangerous sea snakes are found in Malaysia, Indonesia and Myanmar (Burma). About 150 people die every year around the world due to their bites. The photo shows a banded sea krait (*Laticauda colubrina*) near the shoreline of Wakatobi, Indonesia (Photo credit: D. Craig, 9 September 2009)

which stick up when the fish is disturbed or threatened. There is a case known in South Africa in which a fisherman stepped on a stonefish; it poked the second toe of his left foot, through the sole of his footwear, and he died in 1 h (Sergeev 1990).

Lionfish are also recognized as among the most venomous fish in the ocean. They have venomous dorsal spines that are used purely for defence. They inhabit coastal waters of the Red Sea, Indian Ocean and the Pacific islands. Spine punctures cause intense pain, rapidly deteriorating health in 10–15 min, hypopiesis and sometimes paralysis of the skeletal and respiratory muscles (Orlov and Gelashvili 1985). In some cases, people have died because of cardiovascular inefficiency (Orlov 1998).

Fish of the *Siganidae* (rabbitfish/spinefoot) family live in tropical seas. They are not very large and inhabit shallow lagoons. *Three species* are recognized as being the most dangerous; namely, the golden-lined spinefoot (*Siganus lineatus* Val.), little spinefoot (*Siganus spinus*) and the decorated/masked rabbitfish (*Siganus puellus* Schlegel). Their venomous armour comprises 13 dorsal, 4 pelvic and 7 anal spines connected to venomous glands. Systemic effects are similar to those of the lionfish, but weaker.

Toadfish are small benthic fish that inhabit warm coastal waters of America, Europe, Africa and India. The term *toadfish* includes fish from several different families, some of which inhabit fresh water; for example, *Thalassophryne amazonica* is

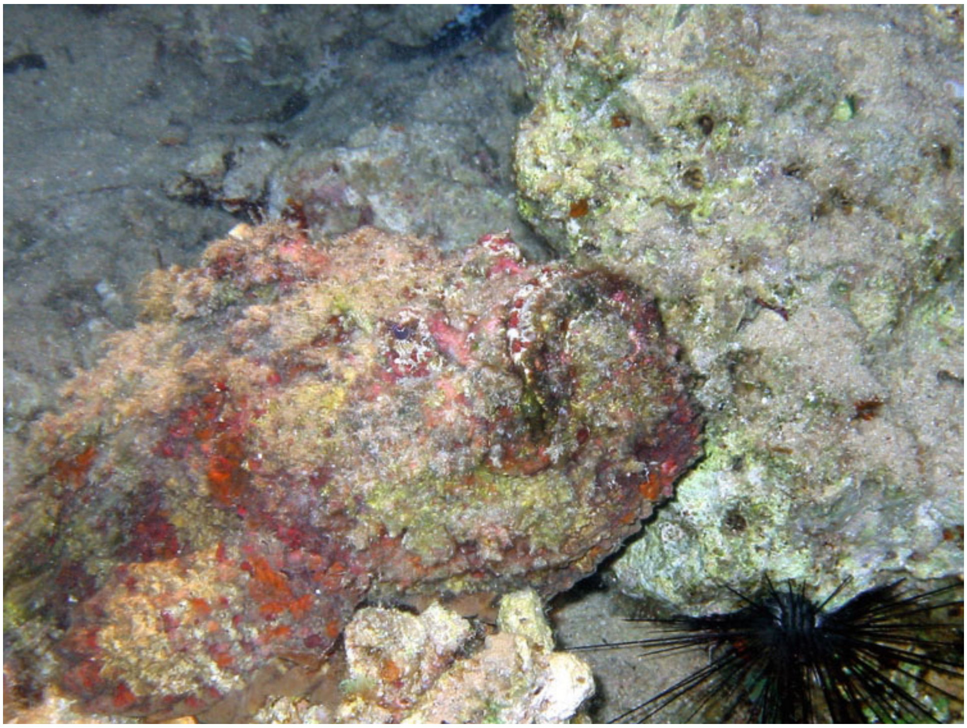

Photo 5.56 The spines on the back of the stonefish are venomous and can penetrate a rubber-soled shoe. The fish is extremely well camouflaged, and care should be taken to avoid stepping on it. The venom can be fatal. The photo shows a stonefish in the Red Sea (Photo credit: http://en.wikipedia.org/wiki/File:Synanceia_nana.JPG)

native to the Amazon River. Its venomous apparatus consists of one spine on each opercle and two dorsal spines; all four spines are hollow and connected to venomous glands. Puncture causes pain that resembles that of a scorpion sting and leads to neoplasm, hyperemia and heat. There are no recorded lethal cases.

Stargazers, or sea cows (Uranoscopidae), are strictly marine fish that belong to the order Perciformes and have eyes on top of their heads (hence their name). They are bottom-dwelling fish, measuring up to 55 cm long, and are 9 kg in weight. They have two venomous spines situated behind the opercle and above the pectoral fins. The Eastern Stargazer (*Kathetostoma laeve*) is the most dangerous; it lives in the eastern Atlantic and Mediterranean. Its wounds can be lethal (Halstead 1970). Stargazers can also cause electric shocks.

Actively venomous *reptiles* include some *snakes*. Freshwater snakes inhabit the southern part of India, countries of the Indochina peninsula, Indonesia, the Philippines and the north-eastern part of Australia. Sea snakes inhabit most tropical coastal waters of the Indo-Pacific (Orlov and Gelashvili 1985). Sea snakes range from 0.3 to 2 m long.

Most *victims of aquatic snakebites* are fishermen working with their nets. Scuba divers who provoke snakes are also at risk. Usually, sea snakes are non-aggressive animals. They are elapid snakes, having two fixed fangs to inject their venom, which is used to immobilize prey or in self-defence. There are *two patterns* of envenoming: myolysis or flaccid paralysis.

The *most dangerous sea snakes* are found in Malaysia, Indonesia and Myanmar (Burma). *Lethal cases* have also been recorded in Oman, Mozambique, India and Japan. There were 1,411 bites with 41 deaths in 17 Malaysian villages (with a total population of 40,100) in 1944–1955. According to J. White (1995), 150 people die every year around the world. The lethality rate of sea-snake bites is 25% (Halstead 1970).

The impacts of fish and reptiles on human activities are illustrated by Photos 5.53–5.56.

Photo 5.57 Pufferfish, including this masked puffer (*Arothron diadematus*), accumulate a neurotoxin called tetrodotoxin in their skin and internal organs. This toxin is extremely potent and has been responsible for many fatalities. The masked puffer is distributed only in the Red Sea (Photo credit: Alan Slater, May 2003)

5.8.2 Poisonous Aquatic Animals

Poisonous aquatic animals are harmful only if they are *eaten*. They can be *subdivided* in the following way: (1) animals that are poisonous permanently, (2) animals that are poisonous periodically, (3) animals that have some poisonous glands and organs, (4) animals that can be toxic only if cooked improperly and (5) animals that have unexplained toxicity. Potentially poisonous groups of aquatic animals basically include fish and molluscs. On rare occasions, ingestion might be caused by meals of holothurians, sea turtles, some marine mammals and sea urchin eggs (Halstead 1970).

Poisonous *echinoderms* include three species of sea urchins. Sea urchins are used as a commercial food source in some countries. Only the gonads are eaten. During the reproductive season of the year, the ovaries of certain species develop toxic products injurious to humans. *Symptoms of ingestion* include stomach pain, nausea and diarrhoea. There are also a few toxic shallow-water holothurians. Improperly cooked, they cause food poisoning, stomach upset, acute gastritis and, in extreme cases, erythrocytoschisis and disruption of the peripheral nervous system.

Most of the harmful passively poisonous *molluscs* belong to the *gastropods. Buccinum* and *Neptunea* (true whelks) cause the most serious poisoning. These molluscs have toxic *salivary glands.* Abalone shellfish have toxic *internal organs.* Eating them leads to unusual consequences: they cause a burning sensation on parts of the body that are exposed to sunlight (Orlov 1998). Babilonia molluscs have poisonous *digestive glands*; they inhabit coastal waters of Japan. Two outbreaks were recorded in Japan in 1957 and 1965 (Orlov and Gelashvili 1985).

Most passively poisonous aquatic animals are *fish*. The most dangerous of these are *blowfish* (Tetraodontidae); *porcupine* or balloonfish (Diodontidae) and *sunfish*/moonfish (genus *Mola).* The Tetraodontidae family is known by many different names, including '*fugu*' which

Photo 5.58 The Tetraodontidae family includes 90 species. They are known by the name 'fugu'. Their liver, eggs, roe (milt) and skin contain tetrodotoxin. The picture shows a tray with six pufferfish of the species *Takifugu rubripes* on sale at the Tsukiji fish market in Tokyo. The fish are sold for consumption at Japanese restaurants. The photo was taken in March 2002 (Photo credit: http://en.wikipedia.org/wiki/File:Fugu.Tsukiji.CR.jpg)

is the Japenese name for pufferfish. Their liver, eggs, roe (milt) and skin contain tetradotoxin. This is a neuro-paralytic toxin that is 150,000 times stronger than the famous curare (arrow poison) toxin (Riccuti 1979). This fish is most toxic during the spawning season, in May through July (Orlov and Gelashvili 1985). In Japan in 1892, 219 people were poisoned by the fish, and 141 of them died (Hallsted 1970).

Fugu, however, is a very popular delicacy in Japan despite its toxicity. People feel a warm sensation all over the body, some excitement, a strange tingling on their tongue and lips, and a slight numbness. Cooking fugu properly is very difficult. Even licensed cooks make mistakes. In 1947, 470 people died after eating fugu in restaurants (Stenko et al. 1984). From 50 to 200 people still die because of fugu ingestion in Japan every year (Riccuti 1979; Stenko et al. 1984; Orlov and Gelashvili 1985; Polenov 2008). The death rate from fugu poisoning was 80% at the end of the nineteenth and beginning of the twentieth century; since then, it has decreased to 11% in Japan and 18% in Thailand (Williamson et al. 1996).

Porcupine/blowfish (Diodontidae) inhabit tropical waters in all oceans. They possess the neurotoxin tetrodotoxin, which is highly poisonous. They are not popular as food, and therefore, there are no many cases of intoxication. Sixty percent of those people who eat the fish die. Death occurs because of respiratory arrest (Halstead 1970).

Ocean sunfish (*Mola mola*) inhabit all warm waters and some seas in the mid-latitudes. Their sizes vary from 0.8 to 3.0 m, and their weights reach 1,400 kg. They have poisonous reproductive products such as eggs and milt, and the liver is also toxic. Symptoms are similar to those caused by diodons. Lethal cases are known (Stenko et al. 1984).

Poisonous fish are also represented in *other taxons*, such as *trunk/cow/boxfish* (Ostraciotidae), which have

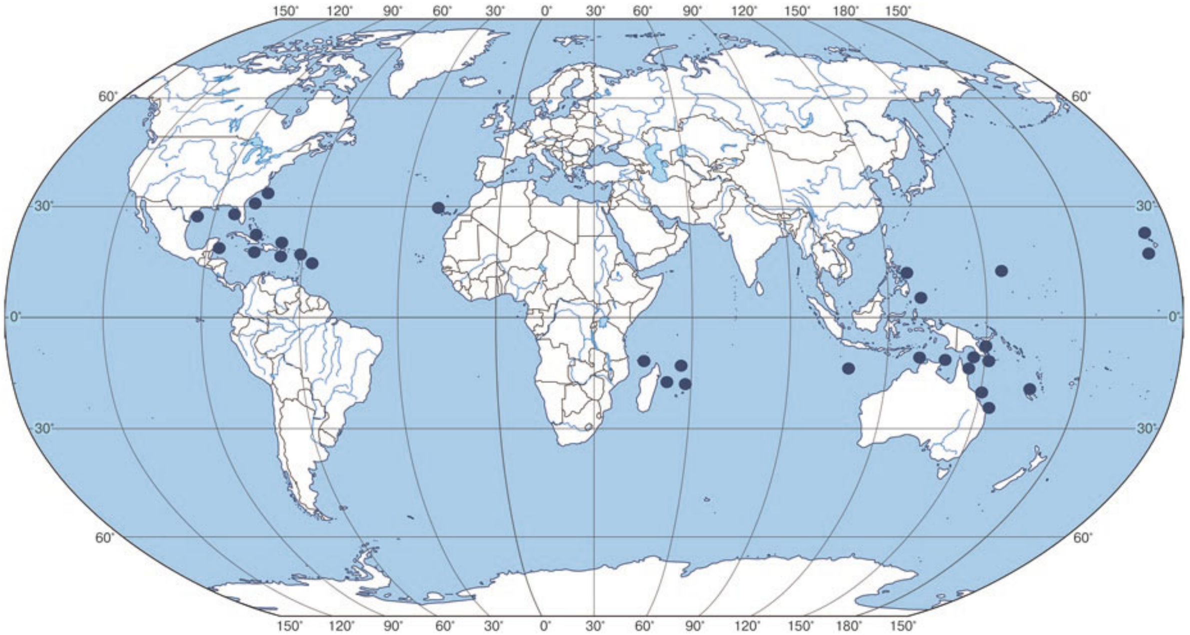

Fig. 5.18 Global distribution of ciguatera fish poisoning (http://www.whoi.edu/redtide/page.do?pid=14899&tid=542&cid=47588&c=3. Reproduced with permission of Woods Hole Oceanographic Institution)

toxic skin mucus and visceral organs; *leatherjackets/filefish* (Monacanthidae), which have toxic reproductive organs and livers; *moray eels,* which have toxic blood plasma; some *sharks*, which have poisonous livers; *barracuda,* which have poisonous eggs, milt and livers; amongst others. *Freshwater* fish are represented by the carp family, including the widely known whiskered *carp*, *marinka* and *osman*. They all have poisonous reproductive products.

There is a large group of fish that do not produce their own toxins but rather receive/ingest them from external sources. Eating these fish can often lead to poisoning. Such cases can be divided into the *following categories* according to the method in which the fish consumed their toxin: (1) poisoning caused by dinoflagellates (ciguatera poisoning) and (2) bacterial poisoning.

Poisoning caused by *dinoflagellates* (*ciguatera*) is an illness casued by eating fish that have consumed toxins. These toxins are not destroyed by conventional cooking of the fish, so the toxin gets passed on to the consumer. It generally relates to reef fish inhabiting waters between latitudes 35°N and 34°S (Ricciuti 1979). Data indicate that there are approximately 400 ciguatera-related species of fish (Stenko et al. 1984; Orlov and Gelashvili 1985). The *most harmful ciguateras* are snapper, surgeonfish, grouper, caranx, seriola, parrotfish, and others. The global distribution of ciguatera fish poisoning is shown in Fig. 5.18.

Symptoms are on *two levels*: *gastrointestinal* (nausea, vomiting and diarrhoea) and *neurological* (headaches, muscle aches and ataxia, numbness and hallucinations). Symptoms can last from just a few weeks to years. Farm-raised salmon can also contain ciguatera (DiNubile and Hokama 1995). From 10,000 to 15,000 ciguatera fish poisoning incidents are recorded annually; the death rate was 7% in the 1960s (Halstead 1970) and dropped to 1% by the end of the 1980s (Russell and Eden 1991). There are no known remedy/effective treatments for ciguatera poisoning.

Sometimes poisoning takes place because of toxic *bacteria* that infect a fish. Cases are widely known that were caused by sturgeon fish infected with botulinus (caused by the bacterium *Clostridium botulinum*, which is prevalent in aquatic sediments). This bacterium is known to produce an extreme neurotoxin. Paralysis of the diaphragm develops and respiratory failure occurs in severe cases, leading to suffocation and eventual death. Six hundred people were poisoned with botulinus toxin from sturgeon in Russia between 1818 and 1918 (Pigulevsky 1964).

Cases of heavy poisoning are also known to result from the consumption of *sea turtle* meat. Some species of turtle become extremely poisonous in waters near the Philippines, Indonesia and Sri Lanka. *Three species* of endangered turtle are known to cause serious illness, as they are likely to contain harmful bacteria such as *Pseudomonas aeruginosa* and *Serratia marcescens*: *green sea turtle* (*Chelonia mydas*), *loggerhead sea turtle* (*Caretta caretta*) and the *leatherback turtle* (*Dermochelys coriacea*). The latter is particularly harmful; 44% of people die after eating the meat. Presumably, symptoms cause generalized inflammation affecting the liver and kidneys (Halstead 1970).

The effects of poisonous aquatic animals on human activities are illustrated by Photos 5.57 and 5.58.

5.8.3 Venomous Terrestrial Animals and Insects

5.8.3.1 Venomous Reptiles

Among *reptiles*, certain snakes and lizards are the only venomous species. Venomous *snakes* are numerous and *widespread reptiles*. The proposed venom clade Toxicofera encompasses all venomous reptiles, including *snakes* (order Squamata, suborder Serpentes) and *lizards* (suborder Iguania [iguanids, agamids, chameleons and other New World lizards]) (Behler and King 1979). There are 270–412 venomous species, according to different data, out of 3,000 terrestrial snakes (Fry et al. 2006). Asia dominates, with 165 such species. There are 91 species in America, mostly in South America; 80 in Australia; 75 in Africa and 8 in Europe (Lipnitsky and Piluy 1991).

It is with great caution that one separates *venomous* and *non-venomous* reptiles. Many of the once classified non-venomous snakes are now considered to produce low concentrations of venom, oftentimes in their saliva. It is also important to note that the most venomous species may not always be the most dangerous; snakes with weaker venom may cause more fatalities due to their distribution in a more populated area. Snakes that are widely recognized for their toxic venom and their relation to humans are noted below:

1. Colubrid snakes (Colubridae);
2. Sea snakes, coral snakes, Taipans, brown snakes, kraits, mambas, king cobra and cobras (Elapidae);
3. Pit, true, fea's vipers and night adders (Viperidae);
4. Atractaspidids such as burrowing asps, mole vipers and stiletto snakes (Atractaspidiae).

Colubrid snakes include approximately two-thirds of all extant snakes. Two genera of colubrid snakes are recognized as being *extremely dangerous* to humans; namely, the *African boomslang* (*Dispholidus typus*) and the twig/bird snake (*Thelotornis kirtlandii*). They are highly venomous and potentially cause death.

Elapine snakes can be as small as 18 cm (*Drysdalia* sp.), or they grow to be as large as the king cobra, at approximately 5½ m. They inhabit many different environments on all continents (except Antarctica). Some are burrowers; others are arboreal, terrestrial, or aquatic. All of them are venomous. Sea snakes are described earlier in Sect. 5.8.1. The most well-known venomous elapine species include the *coastal Taipan* (*Oxyuranus scutellatus*), which is the largest terrestrial snake in Australia and considered one of the top five most venomous land snakes worldwide. Its venom contains a highly toxic neurotoxin called taicatoxin. The *king cobra/hamadryad* (*Ophiophagus hannah*) also ranks in the top five most venomous snakes. Their venom contains both neurotoxic and cardiotoxic properties. Victims will suffer from many symptoms, which can lead ultimately to cardiovascular collapse, respiratory failure and death. The *Indian cobra* (*Naja naja*) causes the most snakebites in India. The venom causes paralysis, which can lead to death due to respiratory failure or cardiac arrest.

All *vipers* (Viperidae) are venomous. Among the most well-known vipers are the *blunt-nosed vipers* (*Vipera lebetina* L.), *common European viper/adder* (*Vipera berus*) and *carpet/saw-scaled viper* (*Echis carinatus* Schneid). Envenomation by these vipers acts in a different way than that by elapid snakes. The causative venom is not a neurotoxin, but rather proteases. The victim therefore can suffer necrosis, a serious collapse in blood pressure and death in extreme cases.

Rattlesnakes also belong to the Viperidae family (subfamily Crotalinae) and are represented by approximately 30 species. The most well known are the *Habu* (*Thrimeresurus flavoviridis*), *jararaca* (*Bothrops jararaca*), *South American bushmaster* (*Lachesis muta*) and *western/Texas diamondback rattlesnake* (*Crotalus atrox*).

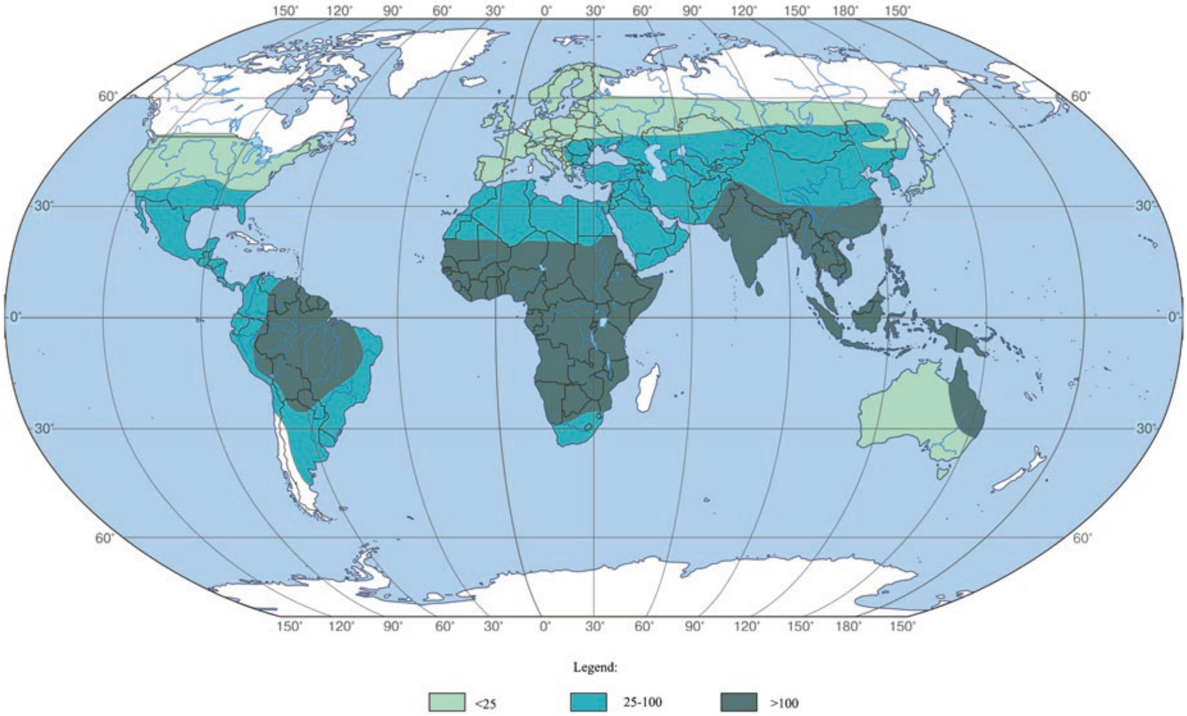

Fig. 5.19 Frequency of snakebite per 100,000 people per year (Adapted from Chippaux (1998), Orlov and Gelashvili (1985), with the author's refinements)

Atractaspididae snakes are in general too small, and their overall venom dosage is also minor. *Atractaspis microlepidota*, however, is one of the larger snakes, growing up to 30 cm long. Symptoms of a bite from this snake include local pain, swelling and numbness. Generally, envenomation is not lethal in adults, but there are known fatal cases in children. The venom is related to the venom of elapid snakes. This group of snakes inhabit the Middle East and Africa.

Not all venomous snakes inject venom when they bite. There are so-called '*dry bites*'. According to different data, dry bites occur in 25% (Thygerson 2006); 30% (Schlexnayder and Schlexnayder 2000); or 50% (Chippaux 2001) of all bites by venomous snakes.

An important factor is the *dose* of venom injected into a victim. For example, the venom of the *mamushi* (*Agkistrodon blomhoffi/Gloydius blomhoffi*) is quite toxic, but the dosage discharged is generally not enough to kill a human. At least, no lethal cases have been recorded (Bannikov et al. 1971). At the same time, the *bushmaster* (*Lachesis muta*) produces a 100 times more venom – enough to kill despite its lesser toxicity (Jorde et al. 1997).

The average snakebite *fatality* rate is 140,000 people worldwide annually (Govorushko 2009a). Also, eight limb *amputation* patients occur for every death that occurs (Tchoua et al. 2002), amounting to one million amputees every year. The frequencies of snakebite per 100,000 people per year in different countries are shown in Fig. 5.19.

Each country has its '*high-priority*' species of snakes, which are responsible for most bites and deaths. For example, in *Guinea,* the true cobra (*Naja*) is responsible for 21.3% out of 963 snakebites; the puff adder (*Bitis*), 15%; various mambas (*Dendroaspis*), 12.4%; and night adders (*Causus*), 12.9%. Another 38.2% were by unrecognized species (Balde et al. 2002). In *Myanmar* (Burma), 70% of all bites were caused by the Russell's/chain viper (*Daboia russelii*) (Chippaux 1998). In *Ecuador*, 80% of bites were related to fer-de-lance (*Bothrops asper*) (Gisneros-Heredia and Touzet 2004). In the state of *Maharashtra*

Photo 5.59 The West African carpet viper (*Echis ocellatus*) is found mainly in West Africa. The maximum length is 65 cm, possibly more, while the average length is 30–50 cm. The symptoms caused by the venom include pain, oedema, tissue necrosis and haemorrhage. The picture was taken at Côte d'Ivoire (Photo credit: J.–P. Chippaux (Institut de Recherche pour le Développement, Cotonou, Bénin))

Photo 5.60 Oedema and phlyctena in a little child due to *Echis ocellatus* after a bite on the right hand. The child was bitten while searching for small animals in a burrow to get food. The picture was taken in North Cameroon (Photo credit: J.-P. Chippaux (Institut de Recherche pour le Développement, Cotonou, Bénin))

Photo 5.61 The African puff adder (*Bitus arietans*) is responsible for more fatalities than any other African snake. This is due to a combination of factors, including its wide distribution; common occurrence; large size; potent venom that is produced in large amounts; long fangs that inject it deeply; their reliance on camouflage, which makes these snakes reluctant to flee; their habit of basking by footpaths and sitting quietly when approached and their willingness to bite. The photo shows gangrene due to *Bitus arietans* in. a cattleman who was driving cattle in North Cameroon (Photo credit: P. Fagot)

Photo 5.62 The Gila monster (*Heloderma suspectum*) is a species of venomous lizard native to the south-western United States and north-western Mexican state of Sonora. A heavy, slow-moving lizard, up to 60 cm (2.0 ft) long, the Gila monster is one of only two known species of venomous lizards in North America. Though the Gila monster is venomous, its sluggish nature means that it represents little threat to humans. The photo shows the head of a Gila monster (Photo credit: Jeff Servoss)

(India), 64.2% of bites are caused by the Indian saw-scaled viper (*Echis carinatus*); 16.6% by cobras (*Naja naja*); 9.8% by the common krait (*Bungarus caeruleus*) and 9.4% by the Russell's/chain viper (*Daboia russelii*) (Punde 2005).

Asian countries where the most snakebites take place include India, Pakistan, Indonesia, Myanmar (Burma), Malaysia and Nepal. In *Africa*, the leaders are Nigeria, Liberia, Senegal, Benin, Côte d'Ivoire and Cameroon; Brazil, Ecuador and French Guinea are the leaders in *South America*.

Agricultural workers are a major group at risk of getting snakebites. They account for 85% of snakebite victims, and most of the bites occur during weeding. *Firewood* and *rock gatherers*, and *stumpers* are also at high risk. Any hand or foot movement is dangerous close to a snake shelter (Chippaux 2001).

Besides humans, snakes also affect *livestock farming* by biting grazing animals.

They bite grazing animals the most. Usually, they bite in the head, not so much in the foot. Horses are among the domestic animals most vulnerable to snake venom; sheep, cattle, and pigs follow (Lipnitsky and Piluy 1991).

Furthermore, snakes actually have an indirect effect on *forestry in some countries*. For example, the female king cobra (*Ophiophagus hannah*) is very aggressive when she is guarding her eggs, and she will attack anyone that comes close to her nest, even elephants. Logging is stopped during this time of year in some Asian countries due to the high mortality of working elephants (Newman 1989).

Regarding *lizards*, only two venomous species are known. The *Gila monster* (*Heloderma suspectum*) inhabits the United States in the Arizona desert, western New Mexico, south-eastern California, southern Nevada, south-western Utah, and in north-western Mexico. *Mexican beaded lizards* (*Heloderma horridum*) live only in Mexico, south of Gila monster habitat (Norris 2001).

Gila monster bites are very rare. Nine accidents related to its bites are described in medical literature (Hooker and Caravati 1994). Usually, these accidents happen due to reckless hunting or keeping them in captivity. Clinical symptoms of envenomation are pain, weakness, dizziness, nausea and vomiting.

The impacts of venomous reptiles on humans are illustrated by Photos 5.59–5.62.

5.8.3.2 Venomous Arachnids

The class of *arachnids* (Arachnida) is divided into 11 orders. With regard to their virulence, the *most interesting orders* are scorpions (Scorpiones), spiders (Araneae) and mites (Acarina).

Scorpions are distributed in a belt between latitudes 48°N and 54°S. There are over 1,750 described scorpion species that belong to 13 extant families. Only a small percentage (<1.4%) of these are dangerous to humans, and practically, all belong to the Buthidae family, (>800 species) and only two belong to Hemiscorpius. The global distribution of the most dangerous scorpions is shown in Fig. 5.20.

In the family *Buthidae*, three species are described as the *most venomous*: the deathstalker, *Leiurus quinquestriatus*; the fattail scorpion, *Androctonus australis* and the scorpion, *Androctonus mauretanicus* (Deal 2006). These scorpions carry a strong mixture of neurotoxins.

There is a specific *composition* of dangerous scorpions in each country. In most countries, only one species dominates. In Tunisia, for example, 80% of all stings and 90% of all lethal accidents are related to *Androctonus australis.* In Zimbabwe, 75.4% of all incidents are associated with *Parabuthus transvaalicus*

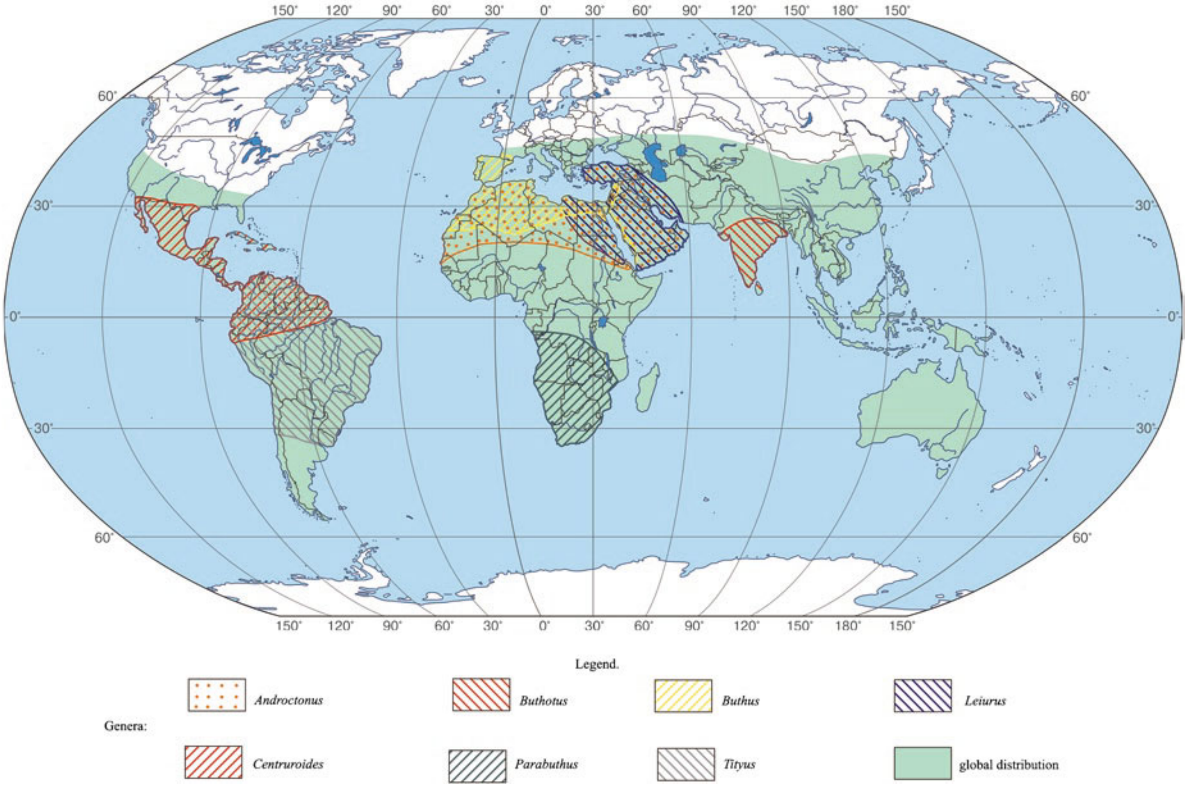

Fig. 5.20 Global distribution of the most dangerous scorpions (Adapted from Handbook of clinical toxicology 1995; http://scorpion.amnh.org/page3/page3.html). Reproduced with permission of Prof. Julian White)

(Bergman 1997). The striped-backed scorpion, *Centruroides vittatus*, is common in the United States and Mexico, where it frequently causes injury to humans (Cheng et al. 2007).

There are *two* dominating species in some countries. In Saudi Arabia, they are the deathstalker, *Leiurus quinquestriatus,* and the fattail scorpion, *Androctonus crassicauda* (Jarrar and Al-Rowaily 2008); in India, the Indian red scorpion *(Mesobuthus tamulus)* and *Palamneits swammerdami* (Bawaskar and Bawaskar 1998) and in Brazil, the Brazilian black scorpion, *Tityus bahiensis* and *Tiyyus serrulatus* (von Eickstedt et al. 1996).

Some countries have *more variety*. In Iran, for example, 45% of accidents are caused by *Mesobuthus eupeus*; 41% by *Androctonus crassicauda*; and 13% by *Hemiscorpius lepturus*. In Colombia, 39% of stings are related to the black scorpion, *Tityus pachyurus*; 24% to the Florida bark scorpion, *Centruroides gracilis*; and 22% to *Tityius asthenes* (Otero et al. 2004).

Burning pain occurs at the site of a scorpion *sting*; the skin flushes and swells, sometimes with blisters. Systemic disturbances are headache, dizziness, weakness, saliva flow, tearing, shortness of breath, cramps and mental impairment (Modern medical encyclopaedia 2002).

In the past, scorpion stings caused *great distress* in some regions. In Durango (Mexico), for example, 1,600 people died out of a total population of 40,000 due to scorpion (*Centruroides* spp.) stings in 1890–1926 (Barbier 1978). At present, hundreds of thousands of people are stung by scorpions worldwide, annually; nearly 5,000 of them die (Govorushko 2010a).

Spiders belong to the largest orders of arachnids, Araneae. Some species of spiders are able to bite (posess chelicera) through the skin of humans and

Photo 5.63 The Arizona bark scorpion (*Centruroides sculpturatus)* is a small (7–8 cm in length) light brown scorpion common to the south-western United States. The bark scorpion is the most venomous scorpion in North America, and its venom can cause severe pain (coupled with numbness and tingling) in adult humans, typically lasting between 24 h and 72 h. Close-up (macrograph) of the barb of an Arizona bark scorpion (Photo credit: J. Adams, 19 September 2009)

warm-blooded animals and are considered dangerous. Some 200 species (0.5%) of extant spiders are known to have potentially lethal bites.

These species can be broken up into *four categories* based on their *level of threat to humans*:

1. The Brazilian wandering spiders (*Phoneutria* spp.), funnel-web spiders (*Atrax* spp.), widow spiders (*Latrodectus* spp.) and the recluse/fiddleback spiders (*Loxosceles* spp.). Lethal cases due to these spiders are numerous and well documented
2. House spiders, including the notorious hobo spider (*Tagenaria* spp.) and tarantulas (*Haplopelma* spp.); representatives of this category are suspected in people's deaths, but actual data on specific cases are not very authoritative
3. Spiders that have venom potentially dangerous to humans include the Australian funnel-web spiders (*Hadronyche* spp.), mouse spiders (*Missulena* spp.) and *Sicarius* species (including the six-eyed sand spider)
4. Eleven other genera that cause stings which cause different levels of pain sensations

Spider venom can be divided by *its mode of action* into two *categories*: *neurotoxins*, which affect the nervous system and *necrotic toxins*, which affect tissues around the bite and, in some cases, affect vital organs. Spiders of the genera *Latrodectus*, *Atrax*, *Phoneutria* and others have neurotoxins. Necrotic venom is characteristic of the genera *Loxosceles*, *Tegenaria*, *Cheiracanthium*, *Sicarius* and others.

Photo 5.64 The brown recluse spider (*Loxosceles reclusa*) usually bites only when pressed against the skin, such as when tangled up within clothes, bath towels, or bedding. Most bites are minor with no necrosis. However, a small number of bites do produce severe dermonecrotic lesions (i.e. necrosis), and an even smaller number of bites produce severe systemic symptoms. The photo shows the consequences of a brown recluse spider bite (Photo credit: Center for Disease Control Archive, Centers for Disease Control and Prevention, Bugwood.org)

South Africa's *Phoneutria nigriventer* and the Australian species *Atrax robustus* are among *the most dangerous* spiders, judging by aggressiveness and venom toxicity. The recluse spider *Loxosceles laeta*, *L. intermedia* and the Brazilian wandering spider *Phoneutria fera* in South Africa; *Loxosceles recluse* and *Latrodectus mactans* in the United States and *Sicarius hunnii* in South Africa might be considered among this number also, based on such factors as their abundance, frequent occurrence in human dwellings, and presence in areas with high human populations (Diaz 2007).

At this time, *lethality* due to spider bites is immaterial and hardly accounts for even one dozen human deaths a year worldwide (Govorushko 2009b). Deaths occur mostly in South America, where only a few people die every year (Arnold 2007a).

Spiders affect *agricultural* practices in some circumstances. For example, Ceylon spiders (*Poecilotheria fasciata*) inhabit coconut palm trees and frequently bite coconut gatherers. Winery workers often suffer from bites by the spider *Mastophora gasteracanthoides*, as these spiders weave their webs on grapevines (Orlov and Gelashvili 1985).

Spiders have a great impact on *farm animal production.* For example, 1,045 different animals were bitten by spiders in Kazalin county in the Syr-Darya region, Russia, in 1896; 276 camels died out of 738; 39 horses out of 192; 5 cattle out of 30 and 20 goats and sheep out of 85. The total loss was 340 animals (Tarnani 1907).

Several dozen species of *mites* are venomous to humans and vertebrate animals. They belong primarily to the genus *Ixodes* (Ixodidae family) and *Ornithodoros* spp. (Argasidae). The best known are the sheep tick or castor bean tick (*Ixodes ricinus*) and the paralysis tick (*Ixodes holocyclus*). The bite of *I. monocycles* leads to flaccid paralysis and frequently to death (Orlov and Gelashvili 1985).

Scorpion stings have the *most serious impacts* on humans. Spiders have *less of an effect*, and mites *even less* again. The impacts of venomous arachnids on human activities are illustrated by Photos 5.63 and 5.64.

5.8.3.3 Venomous Insects and Centipedes

Approximately, 800,000 insect species use venom, or so-called 'chemical defence' (Izmailov 2005). They are divided into *several groups* based on their *method* of venom infliction (Orlov and Gelashvili 1985).

Insects of the *first* group inject venom into the victim's body with specialized stinging apparatus. This group includes different species of bees, wasps, bumblebees, ants and others. Insects of the *second* group use their mouthparts to inject venom. Among these are some species of bugs and larvae of the horsefly, assassin fly, ant-lion fly and others. The *third* group of insects do not have specialized stinging apparatus, but toxins ooze through pores on their legs (blister beetles and lady beetles) or anal glands (some ground beetles and bombardier beetles). Insects of the *fourth* group have stinging apparatus, where a gland is not provided with a muscle compressor, and venom flows passively. Among these are some butterflies and their larvae (Govorushko 2010b).

There are *three types of reaction* to insect stings/bites: focal reaction, general toxic reaction and allergic reaction. The *first* type is marked by reddening, swelling, pain, itching, burning in the zone of the bite and local lymph node enlargement. *General* reactions are distinguished by shivering, hyperthermia, nausea, vomiting, joint pain and headache. General reactions usually occur with multiple bites. *Allergic* reactions are described in Sect. 5.14.2.

Venomous insects largely belong to the *orders* that include: (1) sawflies, wasps, bees and ants (Hymenoptera); (2) beetles (Coleoptera); (3) butterflies (Lepidoptera); (4) bugs (Hemiptera) and (5) true flies (Diptera).

Hymenopterans. Practically all venomous hymenopterans belong to *stinging* insects. Among these are bees and sphecoid wasps (superfamily Apoidea), wasps (superfamily Vespoidea), ants (family Formicidae) and the ichneumon wasp (superfamily Ichneumonoidea). The global distribution of some dangerous hymenopterans is shown in Fig. 5.21.

Representatives of the Apoidea that are *significant to humans* include *bees*, *sphecoid wasps* and *bumblebees*. A single bee sting is very painful, but a mass attack could be lethal – a beehive, for example.

Stings in the head, neck and throat are the *most dangerous*. The lethal dose for an adult ranges from several hundred to a thousand stings. One case is on record in which a victim survived 2,500 bee stings (Mueller 1990).

Compared to the *Western/European honeybee (Apis mellifera)*, its relative the *African honeybee* (*Apis mellifera scutellata*) is much more aggressive (and thus more dangerous). It sends out more workers in response to a threat. More than 1,000 deaths have been caused

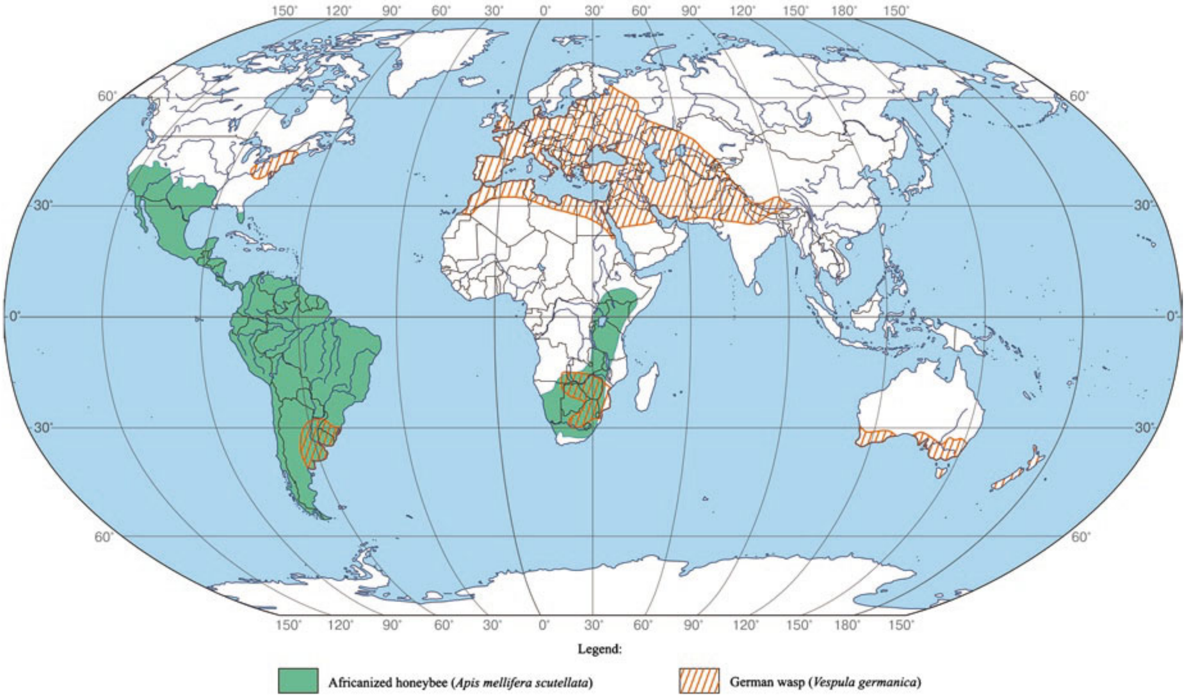

Fig. 5.21 Global distribution of some dangerous insects (Adapted from http://entnemdept.ufl.edu/creatures/misc/bees/AHB.htm; http://en.wikipedia.org/wiki/German_wasp)

by this bee in 40 years. This species causes damage to *farm animals* also. For example, 1,071 attacks on domestic animals were recorded in Trinidad, with 715 deaths, in 1979–1990 (Rodriduez-Laintz et al. 1999). The other dangerous representatives of bees are bumblebees (*Bombus*).

Regarding *wasps*, several species are significant for humans: the common wasp/yellowjacket (*Vespula vulgaris*), European hornet (*Vespa crabro)*, the Asian giant hornet (*Vespa mandarinia*), the endemic Philippine hornet (*Vespa luctosa)*, the Japanese hornet (*Vespa mandarinia japonica*), the European bee wolf (*Philantus triangulum*) and others. Hornets do not have a barbed stinger; therefore, they can repeatedly sting their victim. The endemic Phillippine hornet has the highest toxicity of any known wasp species. Its close relative *V. mandarinia japonica* ranks very high also, but with regard to toxicity and body weight, the former is ranked more toxic. Many cases are known of lethal mass attacks by wasps and hornets on people. Also, cases are on record of death after a single sting to the neck, tongue and roof of the mouth (Tsurikov 2005).

Stinging *ants* have rather strong venom. They belong to the Formicidae family. They constitute a serious epidemiological problem in Australia, Israel and southern states of the United States. In the southern part of the United States, 33,000 people ask for medical assistance every year after being stung by red imported fire ants (*Solenopsis invicta*) of the subfamily Myrmicinae. Hospitalization is required in some cases (Davis and Grimm 2003).

Venomous *beetles* belong mostly to the blister beetle family (Meloidae), flea beetles (Chrysomelidae) and road beetles (Staphylinidae).

Blister beetles can secrete a venomous chemical compound known as canthardin to protect themselves. Beetles squashed on human skin cause blistering and dermatitis. Exposed body parts, such as the arms, neck and face, are most vulnerable (Tsurikov 2005). They

Photo 5.65 Stinging ants have rather strong venom. They constitute a serious epidemiological problem in Australia, Israel and southern states of the United States. In the United States, 33,000 people ask for medical assistance every year after stings by red imported fire ants (*Solenopsis invicta*). The photo shows numerous stings of red imported fire ants in the United States (Photo credit: Murray S. Blum, University of Georgia, Bugwood.org)

Photo 5.66 Wasps are stinging insects. A single wasp sting is very painful, but a mass attack could be lethal. Cases are on record of death after a single shot to the neck, tongue and roof of the mouth. The photo shows a wasp stinger close-up and a venom droplet (Photo credit: http://en.wikipedia.org/wiki/Wasp)

are also harmful to certain animals that ingest them accidentally.

Some representatives of *flea beetles* are highly poisonous. Toxins of the diamphidia flea beetle larva (*Diamphidia locusta* and *D. nigro-ornata*), which live in Africa, are some of the most powerful natural toxins (Orlov and Gelashvili 1985).

Representatives from the *Paederus* genera are the most venomous among *rove beetles*. The Kenya/Nairobi fly is the name given to two species; namely, *P. crebinpunctatus* and *P. sabaeus*. Venom is present in their haemolymph, and therefore, crushing them on your skin will cause the release of a toxin that causes blistering and lichenoid dermatitis. Epidemics of this disease were present in Russia (lower Volga River basin), Brazil, India and Algeria (Orlov and Gelashvili 1985).

Among *butterflies* (Lepidoptera), adults and larvae (caterpillars) can be poisonous. There is a specific composition of poisonous Lepidoptera in each country. In Uruguay, for example, the most dangerous is the larva of *Megalopyge uren.* Its venom can cause, besides very strong focal pain, symptoms of general intoxication expressed in nervous excitement, bradicardia, cramping and vomiting. The larvae of the southern flannel moth (*Megalopyge opercularis*), which is densely covered in venomous hairs (setae), causes the most harm in the south-eastern states of the United States. It causes seasonal epidemics of dermatitis, affecting several thousand people, from June to September (Norris 2002).

Insects with venomous mouthparts cannot sting; they deliver their venom when they bite a victim. Their saliva is poisonous. Such insects belong to the true bugs (order Hemiptera), and others are included in the true flies (order Diptera). True flies are also the vectors of many serious diseases.

Some *true bugs* related to the Reduviidae family can paralyse invertebrates and mammals with their

Photo 5.67 Stink bugs (family Pentatomidae) are common around the world. They produce a nauseous secretion that can cause cutaneous lesions in humans. The photo shows erythematous and oedematous plaques caused by contact with a stink bug on the neck of a human being (Photo credit: Vidal Haddad Jr. (Boticatu School of Medicine, São Paulo State, Brazil))

saliva (Orlov et al. 1990), but they are safe to humans. The subfamily Triatominae (e.g. *Paratriatoma hirsuta*), also known as kissing bugs, are able to transmit the potentially fatal Chagas disease when they bite humans.

Some *horseflies* of the *true flies* are dangerous to humans. For example, larvae of horseflies from the genera *Tabanus* and *Chrysops* cause epidemics in paddy fields in Japan. Pain lasts at the site of the bite from 10 min to 2 days. Erythema appears on the skin, and strong itchiness and enlargement of lymph nodes can develop (Orlov and Gelashvili 1985).

Venomous *millipedes* (Diplopoda) and *centipedes* (Chilopoda) are easily distinguished not only in their anatomical differences but also in their toxicities: centipedes are *armed* venomous organisms, while millipedes are *unarmed* venomous organisms (Orlov and Gelashvili 1985).

Centipedes are predators, killing their prey with well-developed, powerful mouthparts. There are approximately 3,000 species of centipedes described, and approximately 620 are considered medically significant (Vazirianzadeh et al. 2007). Of these, large tropical species (*Scolopentdra moistens*, *Scolopendra gigantean*, etc.) are the most dangerous to humans. The global distribution of some dangerous centipedes is shown in Fig. 5.22.

Millipedes can emit venomous liquids and gas through special pores located along the sides of their bodies. These emissions can cause burning of the skin,

Photo 5.68 There are about 3,000 species of centipedes, and about 620 are considered medically significant. Of these, large tropical species are the most dangerous to humans. The photo shows Dr. 'Ted' Hill, holding a medium-sized specimen of the giant centipede, *Scolopendra gigantea*, in Trinidad in the 1950s (Photo credit: Eleanor Hill)

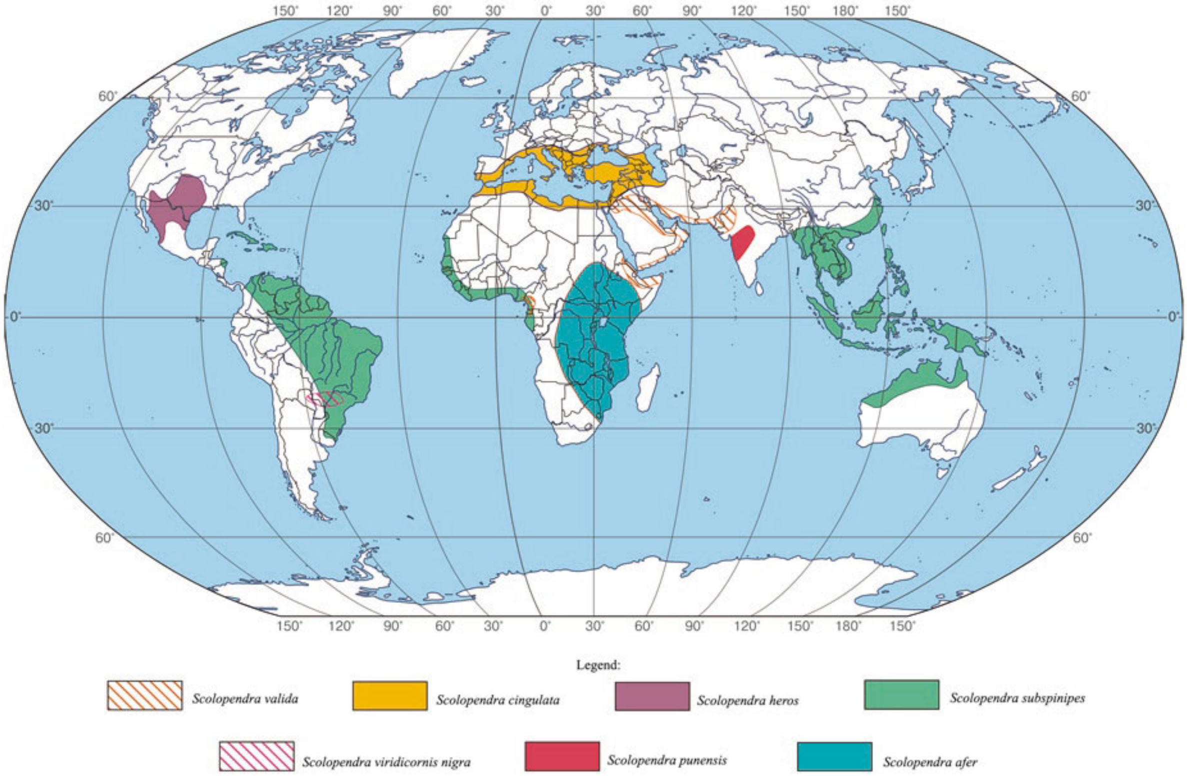

Fig. 5.22 Global distribution of some dangerous centipedes ((www.scolopendra.be. Reproduced with permission of Mr. S. Lenaerts)

creating blisters and sores. If they come in contact with the eyes, they cause sharp pain and inflammation; there is the possibility of keratohelcosis and blindness (Haddad et al. 2000).

Encounters with millipedes *rarely cause death* – there might be a few deaths every year – but the medical importance of millipedes is significant. For example, nearly 5,000 bites are recorded in Turkey every year for which people seek medical advice (Serinken et al. 2005).

The impacts of venomous insects and centipedes on humans are illustrated by Photos 5.65–5.68.

5.8.3.4 Poisonous Amphibians and Mammals

Poisonous amphibians are from two *orders*: (1) batrachian amphibians; that is, frogs and toads (Anura) and (2) tailed amphibians; that is, salamanders (Caudata). All of them are unarmed, actively poisonous animals; that is, they do not have special apparatus to inject venom into the body of a victim or prey. The source of their toxin is via their skin/glands. The global distributions of some venomous amphibians and mammals, and also poisonous birds, are shown in Fig. 5.23.

Dart frogs (Dendrobatidae) are the best known *batrachians.* They inhabit tropical rainforests in Central and South America. The family includes approximately 180 species, all of which are poisonous. Most of them are small frogs 12–19 mm long and colourful. They can secrete a toxin through their skin that can cause a neuroparalytic action. It affects victims by entering the blood through mucous membranes of the eyes, nose and mouth, or through small cuts and abrasions on the skin. It causes arrhythmia and heart failure.

Most poisonous frogs belong to the genus *Phyllobates*. For instance, the skin of a single *golden poison frog* (*Phyllobates terribilis*) contains almost 2 mg of batrachotoxin. This is enough to kill 20 people.

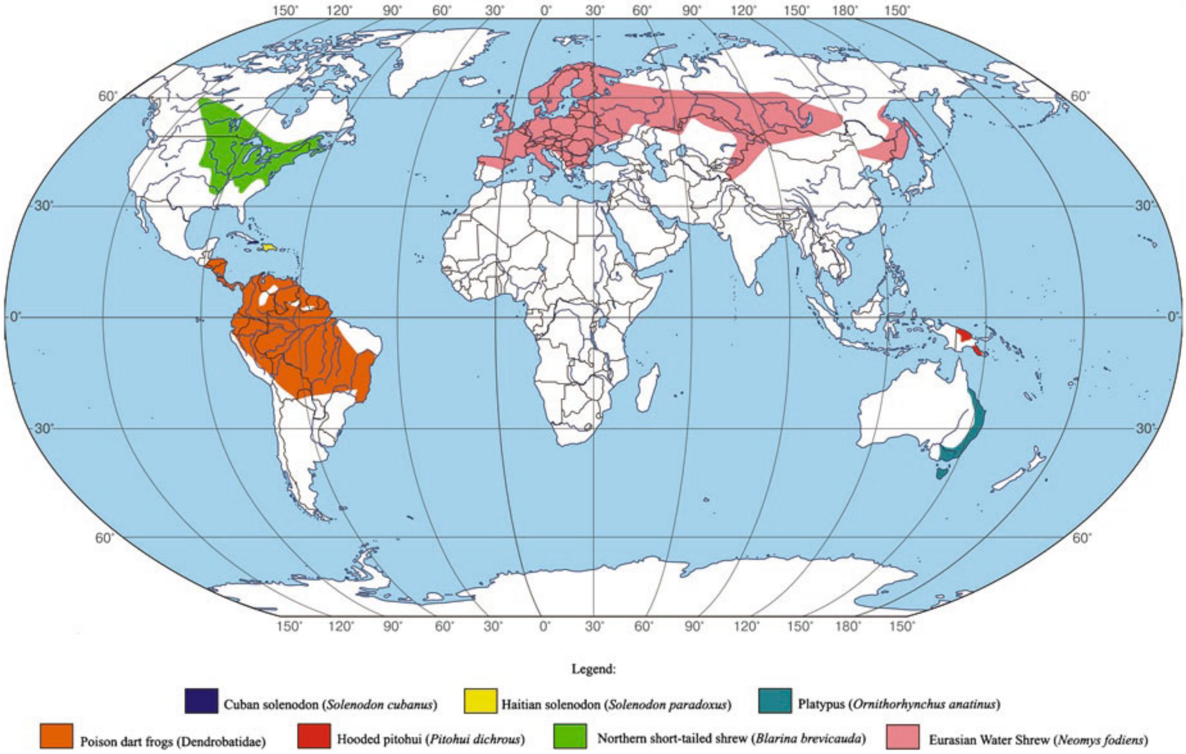

Fig. 5.23 Global distribution of some venomous amphibians, mammals, and birds (Adapted from: http://en.wikipedia.org/wiki/poison_dart_frog; http://researchive.calacademy.org/research/cbri/papua_new_guinea/; http://www.eol.org/pages/1554?category_id=40#media-maps; http://www.edgeofexistence.org/mammals/species_info.php?id=4; http://www.iucnredlist.org/apps/redlist/details/20321/0)

Photo 5.69 Dart frogs inhabit tropical rainforests in Central and South America. Most of them are small frogs 12–19 mm long and colourful. Their venom has neuroparalytic action. The photo shows a red poison-dart frog (*Dendrobates pumilio*). The picture was taken on the island of Bastimentos in the Bocas del Toro province, Panama (Photo credit: Thomas Splettstoesser, 14 October 2008)

Photo 5.70 Toxicity of mammals is very rare. The photo shows a European mole (*Talpa europaea*). Its saliva contains toxins that paralyse earthworms in particular (Photo credit: http://en.wikipedia.org/wiki/European_Mole, summer 2003)

Photo 5.71 Poisonous birds are birds that produce toxins to defend themselves from predators. The photo shows a hooded pitohui (*Pitohui dichrous*), the first poisonous bird identified. It was described in 1989 (Photo credit: http://en.wikipedia.org/wiki/File:Hooded_Pitohui.jpg, 2 September 2008)

The best-known poisonous *true toads* are members of the Bufonidae family. Many representatives of this taxon have a pair of poisonous parotid glands (at the back of their heads) that secrete an alkaloid poison as a defence mechanism. Lethal cases of human intoxication are rare. Domestic animals die more often. Mostly dogs die after recklessly catching toads (Orlov and Gelashvili 1985).

The most poisonous representative of this family is the *cane toad/marine toad* (*Bufo marinus*). This is a large amphibian, measuring up to 25 cm long. The natural habitat of this species is Central and South America. Its poison is dangerous not only through mucous membranes and cuts in the skin but also through undamaged skin. The marine toad is poisonous in all stages of its life. Eggs and tadpoles are dangerously poisonous as well. There is a well-known case in which people died after eating soup accidentally contaminated with marine toad eggs.

Tailed amphibians. Poisonous representatives of this family are some *salamanders, newts* and *water lizards.* The family of true salamanders (Salamandridae) includes over 70 extant species living in Eurasia, northern Africa and North America. The best-known poisonous species of this family is the *fire salamander,* which can exude toxic skin secretions.

This species inhabits central and southern Europe, North America, Algeria, Morocco and western Asia Minor. It has *parotid glands* like the toad. Lethal human cases of poisoning by this salamander are unknown.

The *California/orange-bellied newt* (*Taricha torosa*) is a well-known species. It inhabits the southwestern United States. Its skin is capable of discharging tarichotoxin, which is identical to tetrodotoxin. The neurotoxin is highly poisonous, but it has to be ingested to cause harm. *Eggs* are especially poisonous. Newt toxicity is exceptionally passive, as for all other amphibians. They do not possess any sharp apparatus to cause damage to skin.

Toxicity of *mammals* is very rare. Only a few poisonous species are known. Toxicity is present in egg-laying mammals (order Monotremata) (the platypus and echidna) and viviparous animals (solenodons and shrew mice). Egg-laying mammals inhabit only Australia, Tasmania and New Guinea. They are terrestrial (echidna) or semi-aquatic (platypus) animals. The male *platypus injects its victim* via a spur located on the rear ankle, which is connected to a toxic femoral gland.

Platypus (*Ornithorhynchus anatinus*) venom is more toxic than *echidna* (there are four extant species) venom. No lethal cases in humans have been recorded. Some disorders in the cardiovascular system occurred when people were attacked by platypuses. Dogs have died during hunts of platypuses (Orlov and Gelashvili 1985).

The rest of the venomous mammals belong primarily to two insect-eating families. They have toxic saliva that contains neurotoxins. The family of *solenodonts* (Solenodontidae) is represented by *two species*; namely, the Haitian solenodon/agouta (*Solenodon paradoxus*) and the Cuban solenodon (*S. cubanus*) inhabiting Haiti and Cuba, respectively. Their toxic saliva is dangerous to humans.

Some *shrew mice* (Soricidae) species have toxic saliva. These small animals weigh 2–100 g. Their appearance is similar to that of mice. Venomous species include the *northern short-tailed shrew* (*Blarina brevicauda*), which inhabits the United States and Canada. It can deliver a painful bite to humans. On the other hand, the *Eurasian water shrew* (*Neomys fodiens*), which inhabits banks along freshwater basins in Russia, is unable to pierce the skin of humans. The *southern short-tailed shrew* (*Blarina carolinensis*) inhabits the eastern United States. Its saliva is venomous and can be lethal to mice but not humans. The *European/common/northern mole* (*Talpa europaea*), of the Talpidae family, has saliva that can paralyse earthworms. It is not known to cause injury to humans.

Slow lorises are primates of the *Nycticebus* genus. There are three known extant species. They produce a toxin in their mouths that can cause a painful bite to humans.

The impacts of these animals on humans are illustrated by Photos 5.69 and 5.70.

5.8.4 Poisonous Terrestrial Animals

Only some birds fall into this category. *Poisonous birds* are birds that produce toxins to defend themselves from predators. No species of bird is known to actively inject venom, but some birds are known to be poisonous to touch or eat. These birds usually sequester toxins from animals and plants that they feed on, commonly from poisonous insects (http://en.wikipedia.org/wiki/Toxic_birds).

Poisonous birds belong mainly to the genus *Pitohui*, from the perching birds order Passeriformes. The *hooded pitohui* (*Pitohui dichrous*), the *first* poisonous bird identified, was described in 1989. Ornithologists were catching birds for a survey in New Guinea forests. Captured birds (pitohui) were painfully dabbing and scratching people's hands. People were licking their wounds instinctively, and their lips instantly became numb. Analysis led to the discovery of poison in the birds' skin, feathers and internal organs. The poison was similar to lipophilic alkaloid toxins (batrachotoxin), which is characteristic of poison dart frogs of Central and South America (Izmailov 2005).

The *little shrikethrush* (*Colluricincla megarhyncha*) also inhabits forests of Papua New Guinea but is found further afield in Australia and Indonesia. This species was found to have toxins similar to those of the pitohui bird.

Another poisonous bird species is the *blue-capped ifrita* (*Ifrita kowaldi*), which was found in 2000. It is not related to the pitohui; the ifrit is also a perching bird but

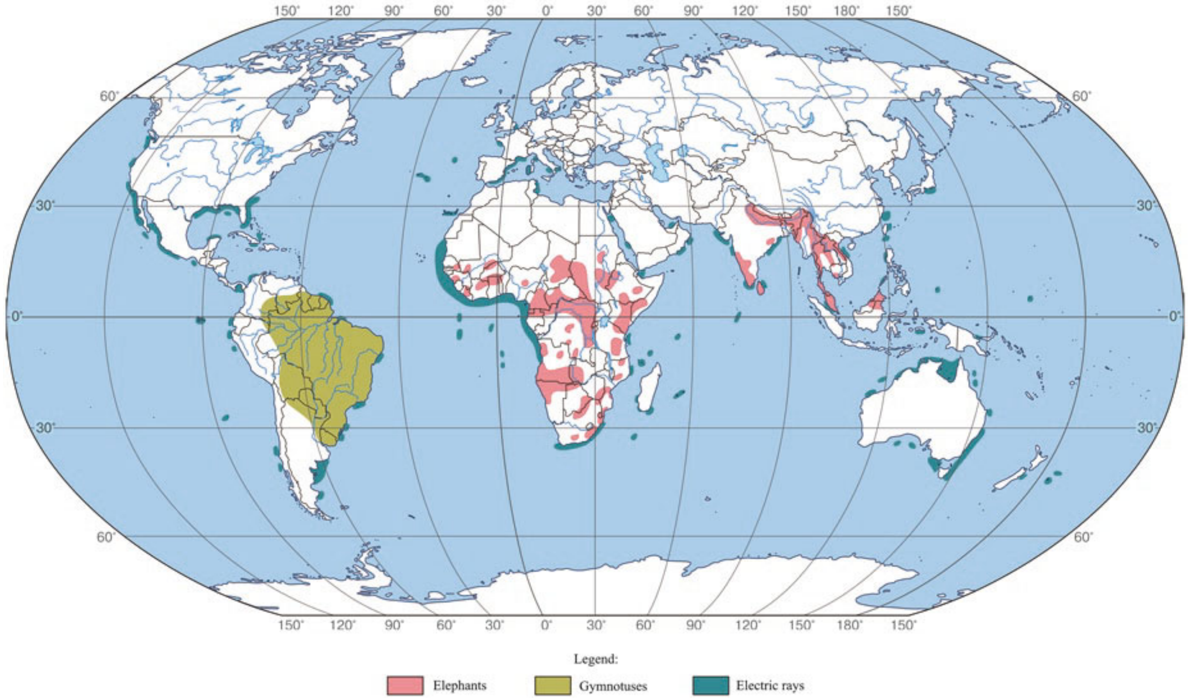

Fig. 5.24 Global distribution of some dangerous animals (www.waza.org; www.iobis.org)

belongs to a different family. It inhabits the same area in New Guinea forests as the pitohui. The exterior of the bird is literally soaked in poison similar to the pitohui toxin. If a predator catches this bird, its mouth will be severely scalded. After that, the poison will mix with the predator's saliva and burn the tissues as it is swallowed. Ifrit's poison can kill a mature tiger in 10 min (http://en.wikipedia.org/wiki/Blue-capped_Ifrita).

The *African spur-winged goose* (*Plectropterus gambensis*) is a remarkable bird also. They are known to feed on the poisonous blister beetle (Meloidae) and then, sequester the beetle's poison into their own tissues. Blister beetles produce the toxin cantharidin, and small amounts of which (as little as 10 mg) can cause death in humans. If the flesh of this bird is ingested by humans, it can be fatal. Certain *quail* populations (*Coturnix coturnix*) are known to be toxic when on specific migration routes. The term *coturnism* means having been poisoned by quail. This disease was so rampant in the Roman Empire that the eating of quail was banned in the first century (Bartram and Boland 2001).

The impact of poisonous birds on humans is illustrated by Photo 5.71.

5.9 Other Dangerous Animals

This category includes animals that are not predators, venomous, or poisonous, but, nevertheless, are capable of causing *injury* or *death* of people. Various *mechanisms* may cause their impact: electric shock, biting, jabbing, kicking, pecking, trampling, etc. People often *provoke* such actions themselves, with their aggressiveness. Some animals are dangerous *seasonally*; in mating season, for instance. Others can cause injury to humans *accidentally* due to their large dimensions or in error. The global distributions of some dangerous animals are shown in Fig. 5.24.

Fish capable of producing electricity are present in both freshwater and marine habitats. Marine species produce *weaker* discharges overall but are still considered dangerous because salt water has *greater conductivity*.

Approximately 348 species are present in freshwater environments and belong to ten different familes. The *elephantfish* (Mormyridae) family has the greatest number of species (203) that can generate an electric field; the *ghost knifefish* (Apteronotidae) has 46 species. The *electric eel* (*Electrophorus electricus*) and the *African knifefish* (*Gymnarchus niloticus*) are the sole species in their families; that is, Electrophoridae and Gymnarchidae, respectively. Freshwater *electric catfish* (Malapteruridae) can discharge an electric shock of up to 350 V.

Electric organs are masses of flattened cells, called electroplates, that are stacked in regular rows along the sides of some fish.

The freshwater *electric eel* (*Electrophorus electricus*) lives in slow-running waters and quiet rivers in South America. They reach 2.7 m long and 0.1 m thick. They have several thousand electroplates and can produce voltages as high as 650 V. The flow of the current is sufficient (0.25–0.5 A) to stun, or even kill, a human. This dangerous pulse of current can be repeated several hundred times every second. A swimmer can drown due to the shock from an electric discharge nearby. The electric organs of the eel take up 75% of their body (Dossier 1985).

Marine electric fish include 24 species of electric rays/torpedos (Torpedinidae). Numbfish are a group of electric rays in the family Narcinidae, which in turn is divided into *two subfamilies*: Narcininae (29 species) and Narkinae-sleeper rays (13 species) The electrical discharge of narcinids (the former subfamily) is *less* than the charge emitted from the marine electric rays. Stargazers (Uranoscopidae) are perciform fish and account for approximately 50 different marine species. They are venomous but can also cause electric shocks.

Electric rays (order Torpediniformes) have an electric organ on either side of their heads or at the base of the pectoral fins that serve as a battery. The strength of their electric charge is less than that of the eel, ranging from as little as 8 V up to 220 V. These charges are used to defend themselves, and although they are considered dangerous, there have been no reported human fatalities. These rays move slowly and are easy to avoid. Symptoms of a charge are tingling, sudden jolt to the body, being stunned, or temporary loss of consciousness. Physicians in ancient Rome prescribed electric discharges from electric rays as a treatment for many illnesses.

The *giant clam* (*Tridacna gigas*) presents some danger. It is a bivalve mollusc with shells up to 1.2 m long and weighs up to 220 kg. Death is possible if it squeezes a diver's limbs between the valves. Deep cuts on sharp edges are another danger. According to E.R. Ricciuti (1979), there are no records on human deaths related to tridacna.

Calamari and *octopuses* may be dangerous to humans. Their sizes vary from 2 cm to 18 m (Dossier 1985). The death of a sailor is described by U. Kromi (1971). On 25 March 1941, after the sinking of the British transport *Britannica*, one sailor was pulled from a life raft by gigantic *squid* tentacles and taken deep under the water. Several cases are described by E.R. Ricciuti (1979) wherein the cause of death was an *octopus* gripping a person's leg. The danger of these animals to humans is extremely low.

Some fish are potentially dangerous to humans. For instance, five cases are recorded of death due to *needlefish* attacks. Usually, such incidents happen to divers on night dives or night fishermen. A flashlight attracts the fish, which jabs with powerful needle-shaped jaws that deeply penetrate the body (Williamson et al. 1996).

Similar injuries and damage are inflicted by *swordfish, marlin* and *billfish* on people using small boats. E.R. Ricciuti's book (1979) describes some cases of such attacks, including lethal ones. There are known incidents of *sawfish* attacks on surfers and boats. D.V. Orlov (1998) discusses such deadly cases.

The *manta ray* (*Manta birostris*) is a marine fish worth mentioning. Several cases are recorded when a manta, attracted by a diver's bubbles, touched an air hose or became entangled in it (Halstead 1970).

Whales could be named as other dangerous aquatic animals. In 1820, the whaleboat *Essex* was destroyed when an enraged whale attacked it (Revyako 1998).

Some *terrestrial animals* cause problems for people: elephants, rhinoceros, hippopotamuses, buffalo, bison, pythons, anacondas, felids, wolves and others. For example, 28,000 *Indian elephants* (*Elephas maximus indicus*) kill an average of 200 people every year (Elephants against people 2003).

Many *bison* attacks are described in the literature. For instance, 57 injuries were recorded in Yellowstone National Park (United States) in 15 years, including two *lethal cases* (Conrad and Balison 1994). Two tourists were killed in the Republic of South Africa as a consequence of *bison* attacks, and there were also *non-lethal attacks*: five by hippopotamuses, three by buffalo, two by rhinoceros, one by a zebra, and one by an elephant. In most of the cases, the animals were provoked by people (Durrheim and Leggat 1999).

The *anaconda* (*Eunectes marinus*) poses danger to humans, which is usually exaggerated. In the opinion of A. Newman (1989), the numbers of human victims of anacondas was sporadic during two to three dozen

Photo 5.72 Needlefish attack divers during night dives. A lantern light attracts fish, and they administer puncturing blows with their needle-shaped jaws. A needlefish penetrated the orbit and entered the sinuses and soft palate – causing loss of the eye, but not proving fatal – in a Japanese diver (Photo credit: Y. Maeshiro, Okinawa, Japan, 13 October 1989)

Photo 5.73 The anaconda (*Eunectes marinus*) poses danger to humans, which is usually exaggerated. Single attacks on people take place, evidently by mistake when a serpent sees a part of a human body under water or it seems that it is subjected to attack. A great anaconda (about 8 m long) in Brazil is shown (Photo credit: Vidal Haddad Jr. (Boticatu School of Medicine, São Paulo State, Brazil))

Photo 5.74 A rare accident with a human being caused by the bite of an anaconda to a fisherman who was half-submerged in a river in Brazil. The snake was medium sized (2 m) and attacked without provocation (Photo credit: Vidal Haddad Jr. (Boticatu School of Medicine, São Paulo State, Brazil))

years. Some trauma can result from *bites* of non-poisonous lizards and rats, *needles* thrust from porcupines, birds *pecking*, etc. (Langley and Morrow 1997). There have been cases of human death caused by *rat bites* (Yanai et al. 1999). Rats carry many diseases.

All together, the impact of this category of animals on human activities is relatively small. However, certain animals in some regions may play a substantial role in deaths of humans from natural causes; for example, the *Indian elephant*.

The impacts of these animals on human activities are illustrated by Photos 5.72–5.74.

5.10 Poisonous Plants

Poisonous plants include those that have some part thereof that is poisonous or, at some time in their life, are poisonous to either animals or humans. They grow predominantly in the tropics and subtropical zones. It is believed that severe and lethal intoxication of humans might be caused by over 700 plants (Narcotic drugs and poisons 1996). *Major groups* of these plants are the following: lower aquatic plants, mostly seaweeds; lower terrestrial plants (mainly fungi) and higher plants.

5.10.1 Lower Aquatic Plants

Both macroalgae and *microalgae* can be poisonous. The most serious problem is *microalgae/microphytes* mass generation, causing the so-called red tides. Microalga toxin producers can be divided into *four groups*: (1) Dinoflagellata, (2) Cyanobacteria, (3) Heterokontophyta and (4) Chlorophyta.

1. The best-known red tides are caused by mass propagation of *dinoflagellates.* There are 5,000–6,000 species, and only 20 cause hazardous algal blooms (Handbook of clinical toxicology 1995).
2. *Cyanobacteria* or blue-green 'algae' are widespread, occuring in both marine and freshwater environments. Algal blooms associated with blue-green algae can cause recreational waterways to be closed due the potential toxicity to both humans and animals.
3. *Yellow-green algae*, or xanthophytes, can be found primarily in clean middle-latitude fresh waters; fewer species inhabit the oceans. Blooms are less related to these algae; only species of the genera *Mallomonas*, *Synura*, *Dinobryon* and *Prymnesium parvum* might cause such blooms.
4. *Green algae* contain chlorophyll; blooms are quite rare and are mostly characteristic of fresh waters (Goryunova and Demina 1974). The total number of toxic microalgae species is about 100 (Dynamics of marine ecosystems 2007).

There are *seven types* of intoxication related to different types of toxins (Sellner et al. 2003): (1) paralytic shellfish poisoning, or PSP; (2) neurotoxin shellfish poisoning, or NSP; (3) diarrhoeic shellfish poisoning, or DSP; (4) amnesic shellfish poisoning, or ASP; (5) azaspiracid shellfish poisoning, or AZP; (6) ciguatera fish poisoning, or CFP and (7) cyanobacteria toxin poisoning, or CTP.

Paralytic shellfish poisoning is the most dangerous and occurs practically everywhere: in North America, Europe, Africa, Asia and Pacific islands. Dinoflagellates produce toxins that cause paralytic shellfish poisoning. About 2,000 cases of paralytic shellfish intoxication are reported in people every year worldwide; lethality occurs in 1–12% of cases of mollusc paralytic intoxication (Arnold 2007c). The global distribution of PSP toxins recorded as of 2006 is shown in Fig. 5.25.

Hazardous algal blooms, which cause *neurotoxin shellfish poisoning,* occur in different areas along the Gulf of Mexico coast, the Caribbean, Florida, North Carolina and New Zealand, but no lethal cases in people are recorded so far (Arnold 2007b). Algal blooms cause mass mortalities of birds and fish near the western coast of Florida. Fish mortalities amounted to an estimated 100 ton per day (Pierce and Henry 2008).

Diarrhoeic shellfish poisoning. Intoxication of this type was first recorded in Japan in 1976. It has been admitted that the poisoning was caused by the dinoflagellate *Dinophysis fortii* (Van Dolah 2000). There were 1,300 such cases reported during the period 1976–1982. Also, about 5,000 cases were reported in Spain in 1981 and 3,300 in France in 1983. Harvesting of mussels was stopped for 1 year in Sweden due to mass DSP in 1984 (Hallegraeff 1993). Similar incidents have been recorded in Canada, South Africa, South America, New Zealand, Australia and Thailand (Van Dolah 2000). No cases of death have been recorded so far (Arnold 2007c).

Amnesic shellfish poisoning. Diatoms in seafood can cause memory loss, brain damage, or even death. It was first mentioned in Canada in 1987 on Prince

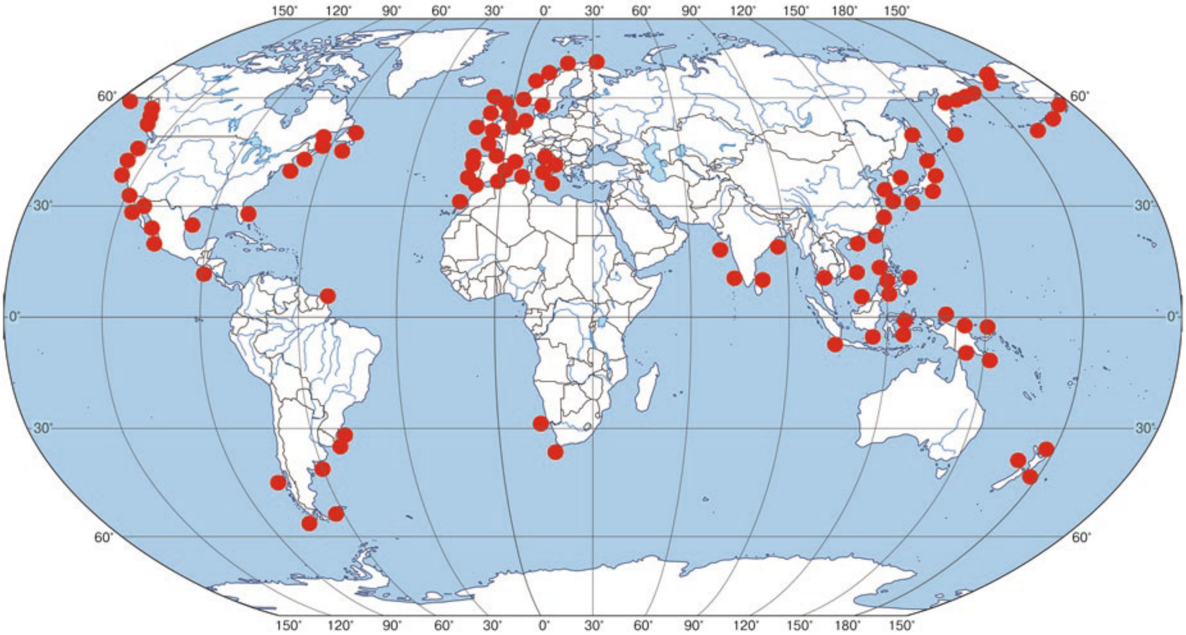

Fig. 5.25 Global distribution of PSP toxins recorded as of 2006 (http://www.whoi.edu/redtide/page.do?pid=14899&tid=542&cid=47594&c=3. Reproduced with permission of Woods Hole Oceanographic Institution)

Edward Island. There were 153 people poisoned after eating mussels; four of them died. The source of intoxication was the diatom *Pseudo-nitzchia pungens,* which were present at a cell density of more than 1 million per litre in local waters. Domoic acid (DA) is a neurotoxin produced by the genus *Pseudo-nitzchia.* Later, this illness became a problem in the states of Oregon and Washington (United States) (Van Dolah 2000).

The *first* recorded case of *azaspiracid* intoxication was in the Netherlands in 1995; eight people were poisoned after eating mussels (*Mytilus edulis*), which were farmed near the western coast of Ireland. Then other cases of the intoxication occurred in Ireland itself, France, Italy and Great Britain; each time, the number of victims was from 10 to 30 persons. Other bivalves are now also known to accumulate the toxin; namely, the Pacific/Japanese oyster (*Crassostrea gigas*), the great/king scallop (*Pecten maximus*), clams (*Venerupis philippinarum*) and cockles (*Cardium edule*). The tiny dinoflagellate species *Azadinium spinosum* found in shellfish produces azaspiracid.

Ciguatera intoxication is the most common disease related to meals served from animals that have accumulated microalgal toxins. It happens mostly in tropical and subtropical areas; 400 million people are at risk (Handbook of clinical toxicology 1995). At least 50,000 similar cases are recorded annually (Van Dolah 2000). The most important intoxication of this type is caused by a dinoflagellate, such as *Gambierdiscus toxicus*.

There are about 400 fish species in total that cause ciguatera intoxication (Handbook of clinical toxicology 1995). Ciguatera intoxication rarely leads to death. Normally, the death rate is about 0.1%, but sometimes it reaches 20%. Death is usually due to respiratory paralysis or hypovolemic shock (Arnold 2007b). Symptoms of poisoning can include both gastrointestinal (sickness, diarrhoea) and neurological (bad headaches, muscle aches, numbness, paralysis and sometimes hallucinations) effects.

Cyanobacterial intoxication. Toxic cyanobacteria species are found in marine, freshwater and brackish waters around the world. Numerous cases are known of mass mortalities of fish, animals and waterfowl, and human poisoning occurs due to the mass development of toxic cyanobacteria (Andreyuk et al. 1990). *Nodularia spumigena* was the first species found among cyanobacteria that can cause the death of animals. *N. spumigena* produces a peptide that is both a cyanotoxin and a hepatotoxin toxic to humans.

Photo 5.75 The impact of toxic algae on fishing is reflected in mass death of fish. The photo shows a massive fish kill resulting from anoxia caused by *Ceratium* in South Africa (Photo credit: Woods Hole Oceanographic Institution)

Cyanobacterial blooms in lakes are a national problem in the United Kingdom, Finland, Norway, Australia and the United States.

Toxic algae affect human health and may be a direct or indirect cause of death. They also have impacts on the following *types of human activity*: (1) aquaculture, (2) fishing, (3) recreational activities and (4) livestock farming. They also have great ecological effects.

It is believed that marine algae are responsible for over 60,000 cases of poisoning worldwide, annually; 1.5% (i.e. 900) of these are *lethal* (Van Dolah 2000). The facts on lethal cases are found in numerous publications (e.g. Hallegraeff 1993; Brusle 1995; Van Dolah 2000; Isla 2001; Dynamics of marine ecosystems 2007).

In addition to poisoning through food ingestion, toxic effects are possible if contaminated air is *inhaled* or contaminated water is *drunk*. For example, from 5,000 to 8,000 people became sick after drinking water from the Ohio and Potomac Rivers (United States) in 1931 (Carmichael 2008). An outbreak of gastroenteritis occurred after people drank water from the Itaparica reservoir in Bahia, Brazil in 1988; 2,000 people became sick, 88 of whom died. Cyanobacteria were the source of the toxin (Teixeira et al. 1993). Also, toxic microalgae lead to gastrointestinal disorders, contact inflammation, itching skin, allergies and other symptoms (Andreyuk et al. 1990).

The impact of toxic algae on *fishing* and *aquaculture* is reflected in mass mortalities of fish and other aquatic organisms. For example, a high mortality of fish was reported in the North Sea and Scandinavian waters in the summer of 1988; it was caused by a dinoflagellate algal bloom, which caused considerable damage to the fisheries of Norway, Denmark and Sweden (Messieh and El-Sabh 1990). The death of many species of flounder, due to massive reproduction of the red-tide dinoflagellate *Gyrodinium aureolum* occurred off the coast of southern Ireland in the summer of 1976 (Brusle 1995). Another bloom occurred again in 1991 (Raine et al. 1993).

The impacts of algal blooms on *recreational activities* are principally associated with aesthetics. Beaches may have a repulsive odour due to putrefaction of aquatic organisms, an unpleasant colour of water, etc. Substantial expenditures are required to clean up beaches afterwards. In Florida (United States), the annual damage is about US$20 million due to dinoflagellate algal blooms (Anderson et al. 2000). Comparable losses have occurred at resorts along the Adriatic coast of Italy due to diatom blooms (Dynamics of marine ecosystems 2007) and in New South Wales, Australia because of mass multiplication of cyanobacteria (Steffensen 2008).

Impacts on *livestock* are mainly due to blue-green algal blooms. Cases of mass mortality of domestic animals and waterfowl, due to multiplication of cyanobacteria, have been observed in many parts of the globe: Australia, the United States, Canada, Argentina, Brazil, 12 European countries, Bangladesh, China, India,

Photo 5.76 Mass death of other aquatic organisms also is a typical consequence of red tides. Clams affected by an *Alexandrium* bloom in South Africa are shown here (Photo credit: G. Pitcher, Woods Hole Oceanographic Institution)

Photo 5.77 Toxic cyanobacteria species are found in seas and in fresh waters. Numerous cases are known of mass death of fish, animals and waterfowl, and human poisoning occurs due to mass development of cyanobacteria. The photo shows a cow killed by cyanobacteria (Photo credit: W. Carmichael, Woods Hole Oceanographic Institution)

Photo 5.78 Red tides can take place in both marine and fresh waters. The photo shows a freshwater red tide in the Italian Alps, species unknown (Photo credit: Woods Hole Oceanographic Institution)

Israel, Japan, Thailand and others (Goryunova and Demina 1974; Stewart et al. 2008).

Economic damage consists of many components: inability to deliver fish and shellfish to market, reduced numbers of tourists, the death of farm animals and others. Available figures on average annual losses in different countries are as follows: United States, US$300–700 million (Dynamics of marine ecosystems 2007); Australia, US$150–200 million (Economic impacts of harmful algal blooms 2008); Japan, US$150 million and Chile, US$40 million (Isla 2001). In addition, damage estimated at tens of millions of dollars occurs annually in France and Italy (Dynamics of marine ecosystems 2007). Presumably, there is a comparable damage in China, South Korea and some European and South American countries. The total damage worldwide is likely to be at least US$2 billion.

The effects of toxic algae on human activities are illustrated by Photos 5.75–5.78.

5.10.2 Lower Terrestrial Plants (Poisonous Fungi)

Fungi (*Eumycota*) can be divided into micromycetes (microscopically small) and macromycetes (higher fungi).

The so-called *'moulds'/mycotoxins* represent the largest and most harmful group among the *poisonous micromycetes*. They belong to different taxa and cause toxic damage to food. According to M. Barbier (1978), over 10% of manufactured food products become inedible (losses of cereals alone are approximately 55 million tons per year) due to mould damage on the planet each year. At present, there are approximately 250 known species of toxic fungi, which produce more than 100 different toxins. They are dangerous pollutants of human food and feed for farm animals.

The *major mycotoxins* are (1) *aflatoxins* (they affect liver tissue and have carcinogenic properties; poisoning comes from eating aflatoxin-contaminated food or feed), (2) *Fusarium toxins* (*Fusarium* fungi produce them and generally attack wheat and barley crops; 'drunken bread' is caused by the use of grain and flour contaminated with *F. graminearum*) and (3) *ergot alkaloids* (these are substances from the fruiting bodies of the parasitic fungus ergot; *Claviceps purpurea* affects more than 150 wild and cultivated herb species; poisonings occur when ergot sclerotia are ingested with grain, flour, or baked bread).

Higher fungi belong to the *macromycetes*. It is believed that there are approximately 5,000 species of these fungi, 200–300 of which are edible, and 50–100 of which are poisonous (Herman and Chyka 2008).

Higher fungi are traditionally divided into *edible*, *conditionally edible*, *almost inedible and poisonous* categories. These concepts are fairly conventional. *First* of all, the same fungus can belong to different categories in different regions. For example, all the mushrooms with acrid, milky juice (including pepper mushrooms, *Lactarius*/milk-caps, etc.) are considered inedible and even poisonous in some countries in Western Europe and America. *Second*, poisoning can be caused by any edible mushroom after prolonged storage of uncooked mushroom or when the shelf life of cooked mushrooms has expired.

Conditionally edible fungi are those that are poisonous in raw form or taste bitter. Poisonous or bitter substances dissolve in water during cooking, and the mushrooms become suitable for human consumption. Mushrooms are conditionally edible also if they can be used after drying, soaking, or other pretreatment.

Inedible mushrooms are those that can not be used in food because of their bitter taste, tough flesh, or unpleasant odour. Representatives of this category include *pepper mushrooms* (*Lactarius piperatus*); *sulphur tuft/clustered woodlover* (*Hypholoma fasciculare*); *poison pie/fairy cakes* (*Hebeloma crustuliniforme)* and *common earthball* (*Scleroderma citrinum*).

Poisonous mushrooms are divided into three *groups* in accordance with the kind of poisoning they cause. The *first group* includes fungi that contain poisons with local action (yellow-staining mushroom – *Agaricus xanthodermus*; undercooked agarical honey – *Armillaria mellea* and some others). They cause gastrointestinal upset, which usually develops 1–2 h after a meal.

The *second group* includes mushrooms that contain toxins which affect the nervous system (Panther cap – *Amanita pantherina var. pantherina*; fly agaric – *Amanita muscaria*; European destroying angel – *Amanita virosa* and fungi of the genus *Inocybe*). Nausea, vomiting, diarrhoea and sweating develop approximately 2 h after the mushrooms are eaten. Then a state of intoxication develops with uncontrolled laughter, crying and hallucinations. There is the possibility of loss of consciousness.

The *third group* of poisonous mushrooms (death cap – *Amanita phalloides*; sulphur tuft – *Hypholoma fasciculare*; etc.) contain toxic substances that affect

Photo 5.79 *Ergot* or *ergot fungi* refers to a group of fungi of the genus *Claviceps*. The most prominent member of this group is *Claviceps purpurea*. This fungus grows on rye and related plants, and it produces alkaloids that can cause ergotism in humans and other mammals that consume grains contaminated with the fruiting structure (called ergot sclerotium) of this fungus. The photo shows ergot on wheat spikes (Photo credit: http://en.wikipedia.org/wiki/Ergot)

Photo 5.80 *Amanita phalloides*, commonly known as the death cap, is a deadly poisonous basidiomycete fungus. It is one of the most poisonous of all known toadstools. It has been involved in the majority of human deaths from mushroom poisoning. The photo shows a warning sign for death cap mushrooms, Canberra, Australia (Photo credit: http://en.wikipedia.org/wiki/Death_cap)

the liver, kidneys and other vital organs. The toxic effects appear very late, after 8–48 h. By this time, irreversible damage has occurred in cells of the vital organs and central nervous system. Death is usual in such cases. Sometimes, it is enough to eat just a half or even a third of a mushroom. The global distribution of the death cap is shown in Fig. 5.26.

From the standpoint of *ethnomycology* (interrelation between humans and fungi), geographical eating habits are very different. Mushrooms are an important food in Russia, eastern and central European countries, China, Nepal, Japan, Nigeria, Malawi, Zambia, Democratic Republic of the Congo and some North African countries (The wild edible mushrooms 2007).

These countries are *major contributors* to human mortality from fungi consumption. For example, people died in Ukraine after eating poisonous mushrooms in 1998, 1999 and 2000: 74, 42 and 112, respectively (Toxic mushrooms 2000). An average of 1,128 cases of fungi poisonings were recorded every year in Russia during 1995–2007, including 66 deaths per year. Between 400 and 450 people die in China every year, 15–20 people in Nepal (Adhikari et al. 2005) and 2.4 persons in Japan (Ishihara and Yamaura 1992).

Between 700 and 800 persons *die* around the world every year. Obviously, China, Russia, Ukraine, Belarus and some Eastern European countries make large contributions to such human mortality. These numbers are

Fig. 5.26 Global distribution of the death cap (*Amanita phalloides*) (Adapted from http://www.eol.org/pages/1009706?category_id=40#media-maps; Wolfe et al. (2009))

consistent with previous estimates of annual mortality rates of several hundred people per year (Jubanyik and Nicoll 2009).

It should be noted that we are talking about *poisoning due to macromycetes*, or higher fungi. It is *not known* how many people die due to poisoning by *micromycetes* (primarily 'mould'). There are no published quantitative data on this subject. There is only a qualitative assessment that micromycetes are more dangerous toxicologically (Orlov et al. 1990).

It is fair to say, with regard to *mortality* from poisoning by *different species of fungi*, that unconditional primacy belongs to the deadly poisonous *death cap* (*Amanita phalloides*). There is the opinion that this mushroom accounts for more than 90% of all such deaths (Paydas et al. 1990; Worthley 2002).

There is a list of *famous people* who died from mushroom poisoning: Euripides, legendary founder of Greek tragedies, his wife and children; the Roman emperor Claudius; Pope Clement VII; King Charles VI of France and the mother of Peter the Great, Natalia Naryshkina. It is believed that the cause of death of all these people was the death cap (http://en.wikipedia.org/wiki/Amanita_phalloides).

The effects of lower poisonous plants on human activities are illustrated by Photos 5.79 and 5.80.

5.10.3 Higher Plants

Alkaloids, glycosides, essential oils, resins, organic acids and corrosive components of milky juice are *major* higher plant *toxins.*

The *number* of poisonous plants in the grass canopy and the degree of their *toxicity* increase from north to south and from the upper zone of mountain vegetation to the lower elevations. The maximum numbers of poisonous plants tend to be characteristic of wetlands and wetland meadows. Typically, leaves are the *most poisonous component*, followed by stems, flowers and fruits (Zhurba and Dmitriyev 2006).

Poison/spotted hemlock (*Conium maculatum*) is among the most well-known poisonous plants. Hemlock greatly damages livestock. For example, *annual financial losses* from hemlock poisoning are estimated at US$40 million in western Texas and eastern New Mexico (James et al. 1992). Losses of cattle because of hemlock are regularly recorded in New Zealand, Canada, Europe and South America (Brooks 2008).

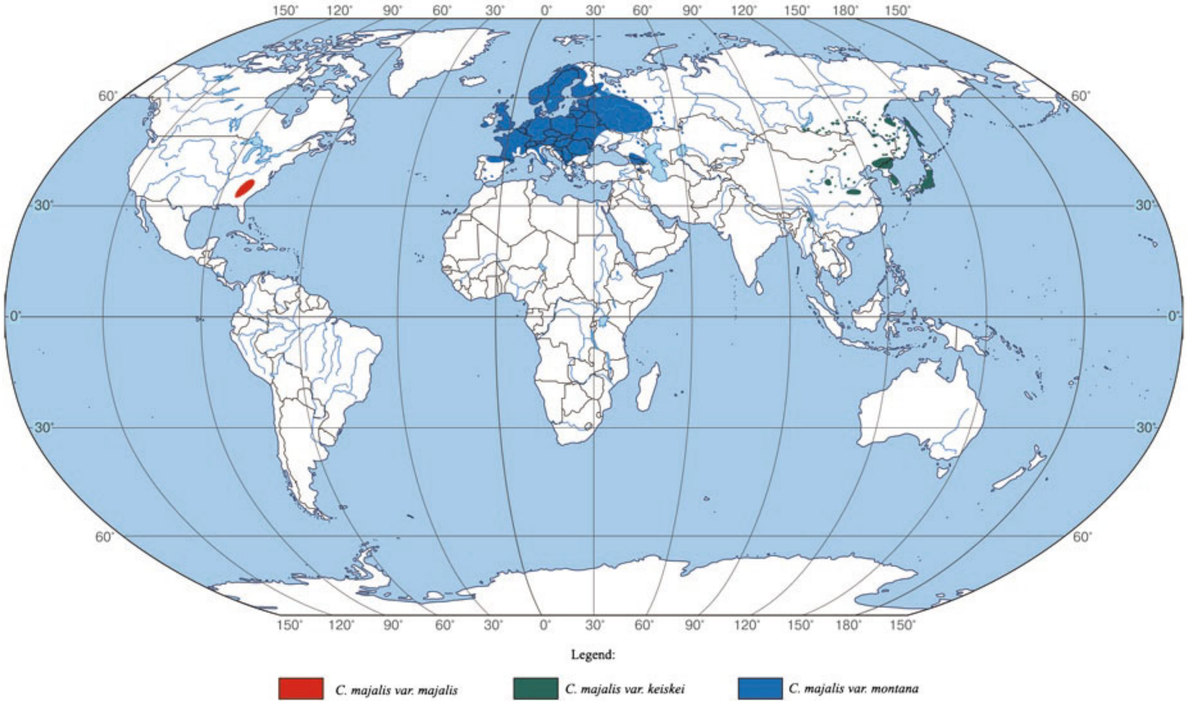

Fig. 5.27 Global distribution of European lily of the valley (*convallaria majalis*) (http://commons.wikimedia.org/wiki/File:Convallaria_majalis_range.png)

People are regularly poisoned by hemlock. The *cause of death* is usually paralysis of the respiratory muscles. This plant is also historically famous due to the use of its sap to take the lives of people sentenced to death in ancient Greece. For example, the Athenian general *Phokion* and the famous philosopher *Socrates* were both killed by hemlock. For a long time, the death of Socrates was believed to be from ingestion of *northern water hemlock/cowbane* (*Cicuta virosa*), but a description of the poisoning symptoms, provided by his student Plato, helped to establish that he was actually poisoned by poison hemlock (Larsson 2004).

Belladonna/deadly nightshade (*Atropa belladonna*) is also well known. The sap of belladonna was often used as a poison in the Middle Ages. There is a historically famous case when Scots destroyed Danes by using belladonna juice. As they retreated, they left barrels of beer, poisoned with belladonna, to the invaders. Deciding to celebrate, the Danes drank the captured drink and plunged into a deep sleep. The Scots came back and easily dealt with their enemies. Soldiers of Napoleon's army were poisoned by belladonna berries when they stood near the German city of Pearn in 1813 (Kutsik et al. 2003).

It is believed that there are approximately 1,000 species of plants that are *harmful* to people (Ismailov 2005). The global distribution of European lily of the valley (*Convallaria majalis*) is shown in Fig. 5.27. Poisonings are especially common in children, who are attracted by bright fruits and flowers. *Children* accounted for 85% of victims (Krenzelok and Jacobsen 1997), but poisonings are more serious in *adults* (Furbee and Wermuth 1997).

Approximately 100,000 people are poisoned by toxic plants in the *United States* each year (Furbee and Wermuth 1997). For example, 122,578 people were poisoned by toxic plants in 1998, 113,864 people in 1999 (Isnar 2001), 77,169 people in 2003 (Brooks 2008) and 60,514 in 2007 (Bronstein et al. 2008). Deaths occur extremely rarely and amount to 5.8 person per year (Panter et al. 1996). In *Switzerland*, 24,950 cases of poisoning were recorded in 29 years (1966–1994) and five people died (Jaspersen-Schib et al. 1996).

Photo 5.81 Cases of mass mortality of animals often occur due to poisoning by toxic plants. Cattlemen survey 700 carcasses of cattle that were killed overnight by a poisonous weed in Australia in 1907 (Photo credit: http://en.wikipedia.org/wiki/File:Cattle_poison.jpg)

On a *global scale,* the loss of life is 1,500–2,000 people per year. The main contribution to this death toll comes from *Sri Lanka.* The main cause of poisonings here are *yellow oleander seeds* (*Thevetia peruviana*). They are popular means of suicide. Nearly 1,100–1,200 suicides occur with the use of the seeds annually (Eddleston et al. 1999). Another large contribution comes from *China*, where mortality is related to different types of *monkshood* (*Aconitum* spp. L.) (Paudel et al. 2008). Jamaica and Burkina Faso are also leaders in such poisonings; most lethal poisonings in these countries are due to consumption of unripe fruits of *ackee* (*Blighia sapida*) (Shepherd 2001).

As for animals, they rank in the following sequence according to their *susceptibility* to poisonous plants (from least susceptible to most susceptible): donkey, mule, horse, cat, dog, pig, poultry, guinea pig, cattle, sheep, goat and rabbit (Zorikov et al. 2007).

The effects of poisonous plants on *livestock* may be direct or indirect. *Direct* effects include loss of livestock, loss of weight, stunted growth, reduced reproductive functioning, miscarriages and birth defects. *Indirect* losses to animal farming are associated with extra costs of building fences (and maintaining them) to prevent cattle from eating poisonous plants, increasing the numbers of herders to reduce poisoning risk, additional safe feed, changing the grazing regime, treating poisoned animals, compensating for loss of feed and fighting poisonous plants. These costs are hard to quantify, but they are present (James et al. 1992).

Cases of *mass mortality* of animals often occur due to poisoning by toxic plants. For example, over 400 head of cattle were lost in a single herd, near the city of Molotov (now Perm) in Russia in 1930; they were poisoned by *cowbane* (*Cicuta virosa*). *Peter the Great* lost more than 500 horses overnight during his military campaign in Persia near the fortress of Kizlyar in 1722; they were poisoned by *wormwood* (*Artemisia*) (Gusynin 1951). Over 6,000 sheep died from *locoweed* (*Astragalus*) in eastern Utah (United States) in 1958 (Nielsen 2009).

Data on losses in 17 western states of the United States give us an idea of the scale of the *economic damage;* they are estimated at US$340 million annually (Allen and Segarra 2001).

The effect of poisonous higher plants on human activities is illustrated by Photo 5.81.

5.11 Bioinvasions

Bioinvasions are penetrations of living organisms beyond their natural range. It may be intentional, when people resettle certain species knowingly; accidental, when they promote relocation indirectly; and naturally, when species move outside of their normal distribution area without human intervention.

There are several *categories* of intentional introduction (Wittenberg and Cock 2001): (1) plants introduced for agricultural purposes, (2) foreign plants grown for use in forestry, (3) non-indigenous plants used for soil improvements, (4) 'aid-traid', (5) ornamental plants, (6) germplasm, (7) birds and mammals released for hunting purposes, (8) mammals released on islands as a food resource, (9) biological control, (10) fishery releases, (11) pets released into the wild and the aquarium trade, (12) reintroductions and (13) releases to 'enrich' the native flora and fauna.

The following are *accidental pathways* of introduction from captivity: (1) escapes from captivity such as from zoos and botanical gardens, (2) farmed mammals, (3) aquaculture and mariculture and (4) research and introduction through research institutes.

Pathways of *accidental introduction* include the following: (1) contaminants of agricultural produce, (2) seed and invertebrate contaminants of nursery plants, (3) seed and invertebrate contaminants in the cut flower trade, (4) organisms in or on timber, (5) seed contaminants, (6) soil-inhabiting species, (7) machinery, equipment, vehicles, armies, etc., (8) hitchhikers in or on packaging material, (9) hitchhikers in or on mail or cargo, (10) hitchhikers in or on planes, (11) ballast soil, (12) ballast water of ships, (13) ballast sediment in ballast water tanks, (14) hull fouling, (15) debris, (16) tourists and their luggage/equipment, (17) diseases in animals traded for agricultural and other purposes and (18) parasites, pathogens and hitchhikers in aquaculture and mariculture (Wittenberg and Cock 2001).

The hundred *most harmful alien species* include 32 species of terrestrial plants; 18 species of terrestrial invertebrates; 14 mammals; 8 species each of microorganisms, aquatic invertebrates and fish; 4 species of aquatic plants; 3 species of birds and amphibians; and 2 reptiles (http://www.issg.org/database/ species/search.asp?st=100ss).

The numbers of accidentally and deliberately introduced alien species are very different for various groups of organisms. For example, the vast number of alien microbial species is introduced *accidentally*. Among insects and marine invertebrates, few species are *deliberately displaced*. At the same time, the majority of alien vertebrates (mammals, birds, fish), by contrast, are *deliberately introduced* (Mack et al. 2000).

There are also vast *differences* in percentages of introduced alien and indigenous native species between different *countries*. Detailed studies have revealed the percentages of invasive species in some countries: United Kingdom, 53%; India, 19%; South Africa, 7%; United States, 6%; Australia, 3%; and Brazil, 1%. The number of introduced species *in the world* as a whole is estimated at 480,000 (Pimentel et al. 2001).

The introduction of alien species of animals, plants and microorganisms in most cases is *irreversible*. Often, these organisms cause serious negative consequences. They may be agricultural or forest pests; vectors of pathogens of plants, animals, and humans; species that cause biodeterioration; and weeds, allergens and other harmful organisms.

Economic losses due to biotic invasions can be divided into the following *categories* (Mack et al. 2000): (1) losses in output (reductions in the numbers of agricultural animals, reduced crop yields, etc.) and (2) the direct costs of combating invasions (quarantine, destruction and control of harmful species, etc.).

D. Pimentel et al. (2001) calculated the damage from invasive species in six countries (United Kingdom, India, South Africa, United States, Australia and Brazil). The average *cost per person* in these countries is US$240 per year. Losses from bioinvasions globally are estimated at US$1.4 trillion.

5.11.1 Microorganisms

The vast majority of bioinvasions of microorganism are *accidental*. Intentional introduction can be attributed only to fermentation yeasts and mycorrhizal fungi (Mack et al. 2000).

In terms of *consequences*, the most significant may be considered to be the introduction of the fungus *Ophiostoma ulmi* in Europe and North America. This fungus is the causative agent of *Dutch elm disease,* and it is spread by a *bark beetle.* Presumably, the original pathogen was brought to northern *France* in 1910 with Chinese workers who were employed by the French government for defence ministry construction work (Krutov and Minkevich 2002).

Later, the disease was reported in the *United States* in 1928. A ship from the *Netherlands* delivered a lot of elm trunks, destined for veneer production, to a furniture factory in Ohio. The wood was infested with the European elm bark beetle (*Scolytus multistriatus*), which carried the pathogen. The disease spread to the south and west, reaching Detroit in the 1950s, Chicago in 1960, and Minneapolis in 1970. The disease spread

Photo 5.82 Introduction of the fungus *Ophiostoma ulmi* in Europe and North America had most dramatic consequences. This fungus is the causative agent of Dutch elm disease. The disease killed over four million elms in the United States between 1933 and 1940. The photo shows an elm drying due to fungus disease in Minnesota (United States) (Photo credit: Robert L. Anderson, USDA Forest Service, Bugwood.org)

to Canada during the Second World War (http://en.wikipedia.org/wiki/Dutch_elm_disease).

Epiphytotics resulted in new areas. For example, in Belgium, 800,000 (60%) out of 1,228,000 were infested in 1918; 30% of the trees were killed in the Netherlands in 10 years. Two million elm trees were affected in England in the 1970s (Krutov and Minkevich 2002). The disease killed over four million elms in the United States between 1933 and 1940 (Elton 2000).

Another famous example is the accidental introduction of the pathogen *Cryphonectria parasitica*, which caused *chestnut blight* in the American chestnut tree (*Castanea dentata*). The disease was imported into North America from East Asia in 1904. This tree had essentially disappeared in eastern forests of the United States by 1940 (Spurr and Barnes 1984).

Introduction of the pathogen *Aphanomyces astaci* became a widely known fact. It causes *crayfish plague*. The causative agent was brought to Italy in 1860 by a US vessel. Its ballast tanks were infested with the red swamp crayfish (*Procambarus clarkii*). The disease quickly devastated crayfish in France and Germany. In 1907, the disease was discovered in Sweden, in 1971 in Norway, in 1972 in Spain, in 1981 in the United Kingdom, in 1984 in Turkey and in 1987 in Ireland (http://en.wikipedia.org/wiki/Crayfish_plague).

Most European species of crayfish were vulnerable to this pathogen. Once it is in water, the disease can be spread in *many ways*: transferred with animals that feed on crayfish (mink, raccoons, otters, migratory water fowl); with boats, hunters and fishermen moving from one pond to another; with natural movement of

Photo 5.83 Crayfish plague, *Aphanomyces astaci*, is a water mould that infects crayfish, which die within a few weeks of being infected. The causative agent was brought to Italy in 1860 by a US vessel. Its ballast tanks contain infected red swamp crayfish, *Procambarus clarkii*. The photo shows a single crayfish with a melanised spot (an immune system reaction) caused by an *Aphanomyces astaci* infection (Photo credit: Thomas Jansson)

Photo 5.84 Kariba weed (*Salvinia molesta*) is originally from south-eastern Brazil and distributed in a range between 24°S and 32°S. It was first introduced in Sri Lanka in the 1930s. From there it spread to India. The photo shows Rankala Lake in Maharashtra, India, covered with kariba weed (Photo credit: Sunil Shaha, College of Engineering, Kolhapur, India)

spores of the fungus downstream; and so on (http://www.american/edu/ted/ CRAYFISH.HTM).

Introduction of the pathogen *Plasmodium relictum* caused significant mortalities of birds on the Hawaiian Islands, due to *avian malaria*. The causative agent of this disease was brought to the islands by settlers, together with infected exotic species of birds. However, a carrier is required to circulate the pathogen. This carrier turned out to be the southern house mosquito (*Culex quinquefasciatus*). Its larvae were transported in water tanks of ships in 1826. Since then, at least 10 species of birds have disappeared from Hawaii, including the colourful red-legged honeycreeper (*Cyanerpes cyaneus*) (http://www.k-state.edu/withlab/consbiol/ IUCN_invaders.pdf).

Consequences of these bioinvasions for human activities are illustrated by Photos 5.82 and 5.83.

5.11.2 Aquatic Vegetation

Invasions of the common *water hyacinth* (*Eichhornia crassipes*) stand out by the scale of their negative effects. It is often called the 'green plague'. South America is the home of this spectacular plant, which has flowers resembling orchids. It was shipped to New Orleans (United States) from Venezuela during an exhibition of cotton in 1884. Visitors were fascinated with the beautiful flowers. They bought seedlings and planted them in their ponds and rivers (Farb 1971).

The plants *quickly multiplied* under the new conditions and covered the surfaces of waters like an all-over carpet. First, it entered Florida, and then, it spread across the South of the United States to Virginia. Then it got into California. Later, the water hyacinth was brought into many countries to decorate ponds. In 1894, it appeared on Java, and then, it spread throughout the islands of Indonesia and moved to the Philippines, Australia, some Pacific islands (Fiji, Hawaii, etc.).

In 1902, it came to *Vietnam* and *India*; in 1905, it appeared in *Sri Lanka* (Ceylon). In 1952, it began to grow vigorously in the *basin of the Congo River*, and later, it appeared in *Cameroon*. Then, it came to *East Africa*. After 1958, the hyacinth was overgrowing rivers of the *Nile* basin; in 1959, it was already widely present in *Sudan*, from Juba to Khartoum (Dorst 1968). Currently, it is found in more than *50 countries* on five continents (www.issg.org/booklet.pdf).

Photo 5.85 A ship blocked by water hyacinth in Winam Bay (Kisumu port, Kenya). In the countries adjacent to Lake Victoria, abundant masses of water hyacinth are called 'green icebergs' since, driven by seasonal trade winds, they alternately migrate to the shores of Kenya, Tanzania and Uganda. The port of Kisumu is blocked by water hyacinth from late December till early May every year (Photo credit: N.R. Robertson, Aquarius Systems Inc., January 1999)

Water hyacinth mats *clog waterways*, making boating, fishing and almost all other water activities impossible. They dramatically impact *water flow*, block sunlight from native aquatic plants, and make *oxygen* less available, often killing fish (or turtles). The plants also create prime habitat for mosquitoes, classic vectors of disease and a species of snail known to host a parasitic flatworm that causes schistosomiasis (snail fever) (http://en.wikipedia.org/wiki/Water_hyacinth).

Kariba weed (*Salvinia molesta*) is originally from south-eastern Brazil and distributed in a range *between 24°S* and *32°S*. It was first introduced on Sri Lanka island in the 1930s (Mavrischev 2000). From there, it spread widely in many tropical and subtropical regions: India, Indonesia (especially Java island), Malaysia, Papua New Guinea, Australia, North Island of New Zealand, many countries in Southeast Asia and southern Africa. This fern was found in the southern United States (Alabama, Texas, Mississippi, South Carolina, North Carolina, Louisiana and Florida) and Hawaii in 1997. *Secondary distribution* of the fern ranges from *35°S* up to *30°N* latitude (Rejmanek 2000).

The typical purpose for the distribution of the plant was for use in *aquariums* and *garden ponds*. This fern was sold under numerous names: water velvet, water moss, salvinia water velvet, salvinia, giant salvinia, African pyle, aquarium water moss, kariba weed, water fern and coi kandy. *Salvinia molesta* entered open waters from aquariums through sewers, and then, it *reproduced very quickly* as a water weed. In ideal conditions, it doubles its numbers every 2.2 days. So, if a single plant is put in a pond, there will be 8,000 of them in 1 month, 67 million in 2 months and 4.5 trillion in 4 months (http://www.saj.usage.armymil/conops/apc/salvinia. pdf).

The *way it grows* is another reason why it is sometimes called the worst weed of the world. It reproduces

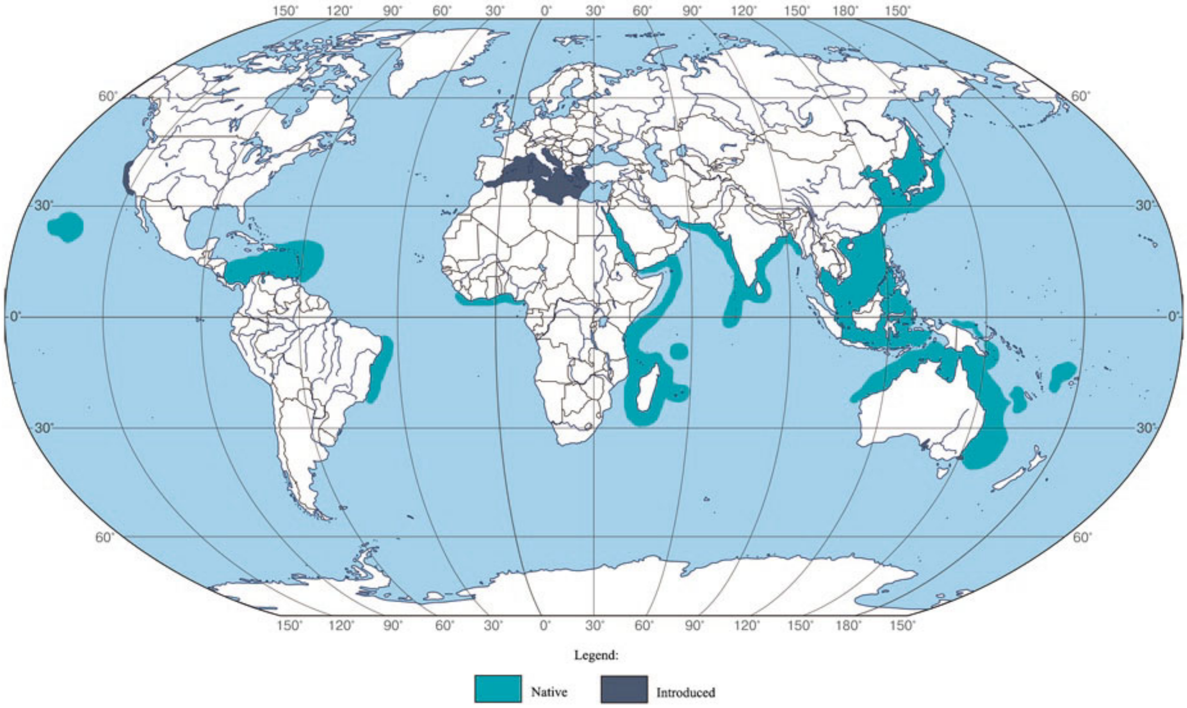

Fig. 5.28 Global distribution of *Caulerpa taxifolia* (http://www.sbg.ac.at/ipk/avstudio/pierofun/ct/caulerpa.htm. Reproduced with permission of Dr. P. Madl. University of Salzburg, Austria)

by dividing itself into pieces. Boats cut through the layer of free-floating ferns and break them into parts, which then grow into new plants. Water surfaces might be covered with floating mats 60 cm thick. They *block waterways*, making fishing and boating impossible, and they complicate irrigation. They also obstruct sunlight needed by other aquatic plants, and they reduce the *oxygen* content in the water (http://en.wikipedia.org/wiki/ Salvinia_molesta).

Introduction of the *seaweed Caulerpa taxifolia* was unintentional. This alga is widespread in most tropical seas. It is thought that the seaweed was accidentally released into coastal waters of the Mediterranean Sea just below the Oceanographic Museum of Monaco in 1984. Now, it has spread into coastal waters of Monaco, France, Italy, Spain, Croatia and Tunisia. It spreads to new areas by attaching to boat anchors and fishing nets, as well as by deliberate release from aquariums. Divers discovered a patch of *Caulerpa* measuring 20 m by 10 m in a lagoon near San Diego in the United States on 12 June 2000. It is thought that the infestation occurred after somebody emptied a fish tank into a storm-water drain (www.issg.org/booklet.pdf). The plant was found on the southern coast of Florida in the same year (http://www.issg.org/ database/species/ecology.asp?si=115&fr=1&sts=). The present global distribution of *Caulerpa taxifolia* is shown in Fig. 5.28. Uncontrolled development of this alga dramatically reduces biological diversity.

Consequences of these bioinvasions for human activities are illustrated by Photos 5.84 and 5.85.

5.11.3 Terrestrial Plants

Bioinvasions by terrestrial plants include the following *stages*: (1) introduction (plants appear in an area outside of their native habitat and reach their adult stage); (2) colonization (plants develop into a new self-perpetuating population) and (3) naturalization (species spreads widely, creating new self-perpetuating populations) (Richardson et al. 2000).

Most invasive species are introduced *deliberately*. Nevertheless, many of them are recognized later as

Photo 5.86 Introduction of kudzu (*Pueraria lobata*) in the United States is a striking example of negative environmental consequences. It causes significant harm to other plants. It overwhelms them with its dense foliage, wraps around stems and the trunks of trees, and breaks branches with its weight. At the present time, kudzu occupies a territory of 20,000–30,000 km^2, and US$500 million is spent annually to fight it (Photo credit: Kerry Britton, USDA Forest Service, Bugwood.org)

harmful (weeds in pastures and crops, allergens, toxic plants, species causing ecological damage, etc.). For example, 463 foreign plant species were introduced to Australia in 1947–1985 to expand the assortment of pasture grasses; 60 of these species were found to be harmful (Mack and Lonsdale 2001).

Introduction of *kudzu* (*Pueraria lobata*) in the United States is a striking example of such negative effects. An exhibition devoted to the 100th anniversary of the United States was held in Philadelphia in 1896. The Japanese government sent professionals there to create a beautiful garden. Large leaves and fragrant kudzu flowers attracted the attention of American gardeners, who started to use it as an *ornamental* plant. It became *cattle feed* in the 1920s. The plant was actively planted to combat soil erosion during the Great Depression (http://www.cptr.ua.edu/kudzu/).

Gradually, it became clear that kudzu causes significant *harm to other plants*. It overwhelms them with its dense foliage, wraps around stems and the trunks of trees and breaks branches with its weight. Rooted kudzu grows rapidly, extending to 18 m in length at rates of about 30 cm/day during the vegetative period (http://www.nps.gov/plants/alien/fact/pulo1.htm). At the present time, kudzu occupies a territory of 20,000–30,000 km^2, and US$500 million is spent annually to fight it (http://en.wikipedia.org/wiki/Kudzu# cite_note-23).

Spanish flag/*West Indian lantana* (*Lantana camara*) is an evergreen shrub 1–1.5 m tall. Its natural habitats are Mexico, Central America, Colombia and Venezuela. It was introduced into India as an ornamental plant in the early nineteenth century, and it appeared in Australia in 1841. This plant was introduced to many tropical and subtropical regions of our

Photo 5.87 Prickly pears (mostly *Opuntia stricta*) were imported into Australia in the nineteenth century for use as a natural agricultural fence and in an attempt to establish a cochineal dye industry. They quickly became a widespread invasive species, rendering 40,000 km^2 (15,000 square miles) of farming land unproductive. The moth *Cactoblastis cactorum* from South America, whose larvae eat prickly pear, was introduced in 1925 and almost wiped out the population. There is a monument to *Cactoblastis cactorum* in Dalby, Queensland, commemorating the eradication of the prickly pear in the region (Photo credit: http://en.wikipedia.org/wiki/Prickly_pears_in_Australia)

planet. In some places, it became a malicious *weed*, occupying many millions of hectares of pasture. Also, Spanish flag is a serious problem for 14 major crops, including *coffee*, *tea*, *rice*, *cotton and sugar cane* (Sharma et al. 2005).

The *strawberry guava* (*Psidium littorale var. cattleianum*) is native to Brazil, but it was naturalized in Florida, Hawaii, tropical Polynesia, Norfolk Island and Mauritius for its edible fruit. It forms thickets and shades native vegetation in tropical forests and woodlands. It has devastating effects on native habitats in Mauritius, and it is considered the worst plant pest in Hawaii, where it has invaded a variety of natural areas (www.issg.org/booklet.pdf).

Annual economic damage from invasive terrestrial plants is very high – US$26 billion for the United States alone (Pimentel et al. 2000) and an estimated AU$3 billion in Australia (Mack and Lonsdale 2001).

Consequences of these bioinvasions for human activities are illustrated by Photos 5.86 and 5.87.

5.11.4 Aquatic Invertebrates

The *Chinese mitten crab* (*Eriocheir sinensis*) is a striking example of an aquatic invertebrate bioinvasion. It is a medium-sized burrowing crab that is native to coastal estuaries of eastern Asia, from Korea in the north to the Fujian province of China in the south (http://en.wikipedia.org/wiki/Chinese_mitten_crab). Human activities have led to its wide distribution throughout the world. First, the crab was shipped with

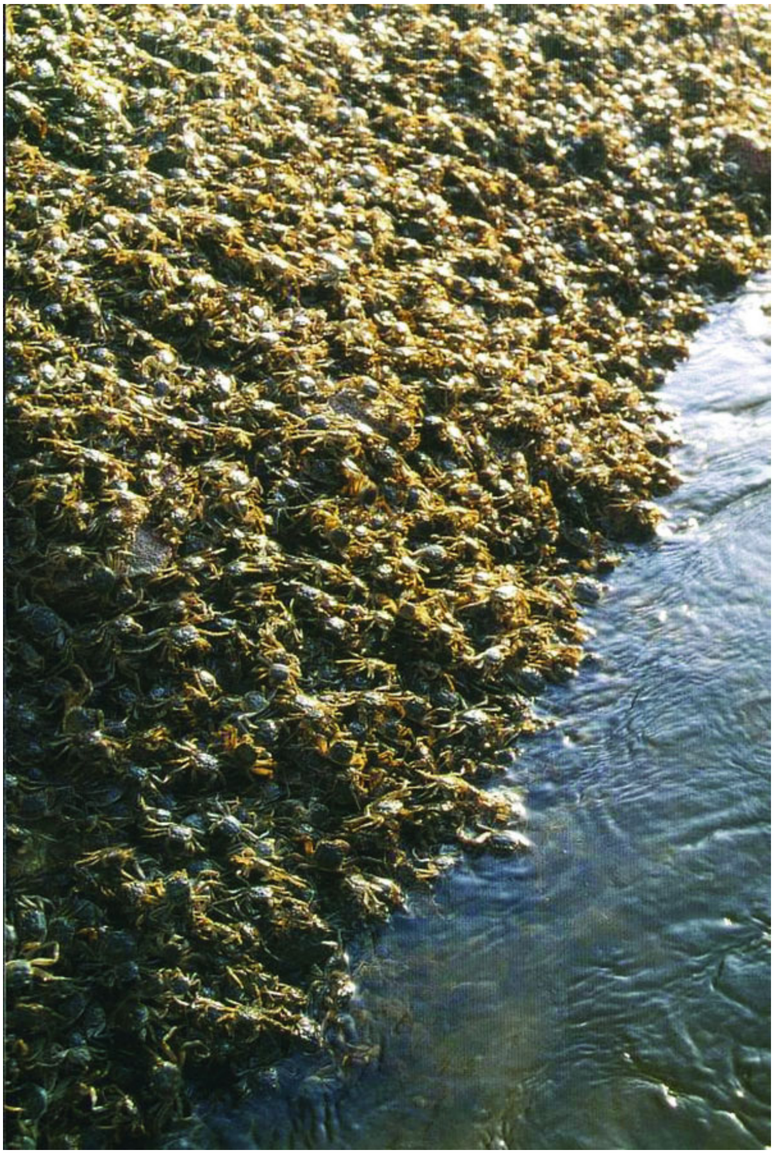

Photo 5.88 The Chinese mitten crab (*Eriocheir sinensis*) was shipped with ballast waters to Germany from eastern Asia. It contributes to the local extinction of native invertebrates and modifies habitats. As well as causing erosion by its intensive burrowing activity, the crab may cost fisheries and aquaculture industries several hundreds of thousands of dollars per year by stealing bait and feeding on trapped fish. The photo shows a crowd of Chinese mitten crabs on a shore (Photo credit: Stephan Gollasch, Hamburg, Germany)

ballast waters to Germany, where it was found in estuaries of some rivers of this country as early as 1912. After multiple shipments to Europe, the crab established stable self-reproducing populations and began to spread further. The population had reached an estimated ten million Chinese crabs in German rivers by the early 1930s.

Then the Chinese mitten crab entered the *Baltic Sea* through the Kiel Canal, and it spread down to the Gulf of Bothnia and the Gulf of Finland. *Eriocheir sinensis* was detected in *North America* in the Detroit River in 1965. In 1973, it was first caught in the Great Lakes. Then the crab was found on the Pacific coast in San Francisco Bay in 1995. The number of crab burrows in rivers flowing into the bay reached 34/m^2 (Biological invasions 2004).

The Chinese crab turns into an extremely *harmful* creature because of its extraordinary fertility: it alters native underwater habitat, destroying aquatic plants; it competes with useful species of crustaceans; it digs banks and dams, causing landslides (being an excellent navvy, this crab digs holes 80 cm deep and 12 cm wide) and finally, it makes it difficult to catch fish, damaging nets and blocking the openings of creels (Dorst 1968).

The *zebra mussel* (*Dreissena polymorpha*) is another famous bioinvasion case. It is a species of small freshwater mussel, an aquatic bivalve mollusc.

Photo 5.89 The zebra mussel (*Dreissena polymorpha*) was originally native to the Caspian and Black Seas. In 1988 zebra mussel larvae reached North America with ballast waters and rapidly colonized the Great Lakes. Damage caused by introduction of the zebra mussel is due mainly to the biofouling abilities of the mollusc. Control of *Dreissena* in 2002 alone cost US$4 billion. The photo shows zebra mussels on a boat motor (Photo credit: Steve Krynock, Michigan Sea Grant)

Photo 5.90 The zebra mussel dramatically reduces water-transmitting capability, inhabiting the pipes of municipal water supplies, nuclear and hydroelectric power plants and various industrial enterprises. The photo shows drinking water screen blocked with zebra mussels in an Irish water supply (Photo credit: F. Lucy, Institute of Technology, Sligo, Ireland)

This species was originally native to the lakes of southeast Russia. *Dreissena* became one of the exotic mollusc species that spread rapidly into river systems of central Europe in the nineteenth century (primarily on the Danube and Dnieper), and it soon was found at the London docks in 1820. The range of the species expanded even further by 1988: zebra mussel larvae reached North America in ballast waters and rapidly colonized the Great Lakes. Later, they invaded several major river systems, including the Mississippi, Hudson and St. Lawrence (Ricciardi et al. 1998). It arrived in Irish waterways in 1993–1994 (Minchin et al. 2005).

Damage caused by the introduction of the zebra mussel is due mainly to the biofouling abilities of the mollusc. It reduces *culvert capacity* dramatically, inhabiting

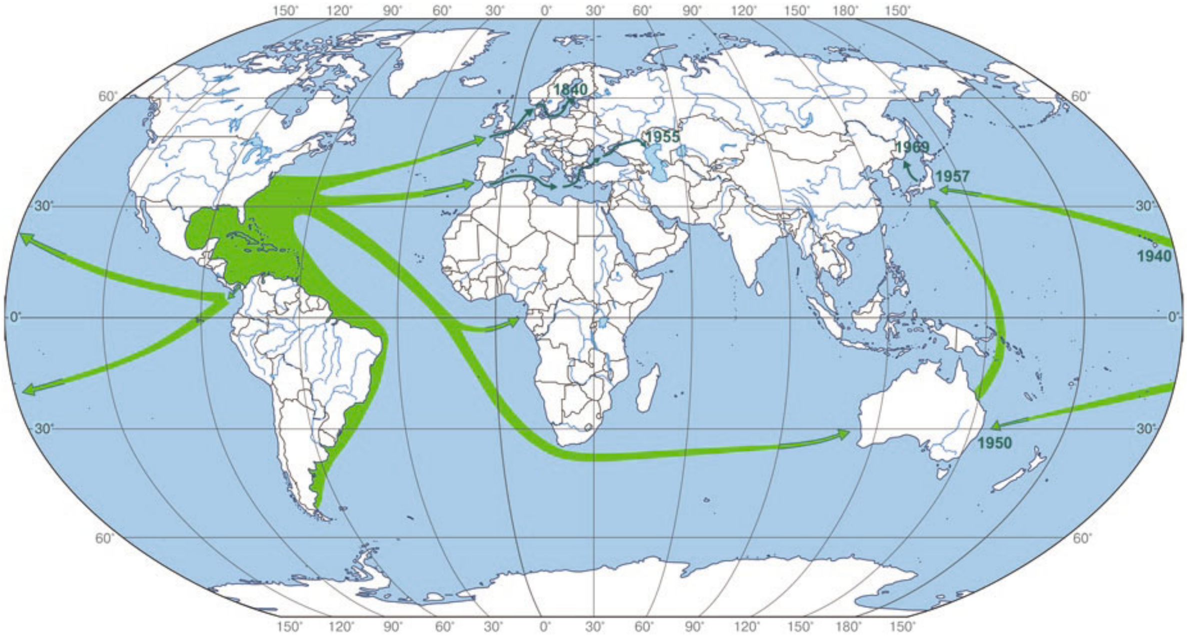

Fig. 5.29 Settling of barnacles (*Balanus improvisus*) (Adapted from Zevina (1972); www.caspianenvironment.org; www.zin.ru; www.rsnz.org; www.marine.csiro.au)

the pipes of municipal water supplies, nuclear and hydroelectric power plants and various industrial enterprises.

The *water supply* was stopped for three days in the city of Monroe, Michigan (United States) in 1989, since municipal water pipes were clogged with these molluscs. Zebra mussel fouling also occurs on all watercraft and abandoned fishing gear (http://www.glsc.usgs.gov/information/factsheets/zebra_mussels00/zebra_mussels00.htm). Control of *Dreissena* in 2002 alone cost US$4 billion (Biological invasions 2004).

The *northern Pacific seastar* (*Asterias amurensis*) mainly inhabits the coastal waters of the Sea of Japan. Then, it was discovered in the port of Port Phillip Bay, Tasmania in the early 1980s. It is believed that larvae were brought there from Japan in ballast waters. Within 2 years, the number of these starfish was estimated at 12 million. Later, they spread widely throughout the southern coast of Australia.

The northern Pacific starfish is a *voracious feeder*, preferring mussels, scallops and clams. It will eat almost anything it can find, including dead fish and fish waste. The seastar is considered to be a serious pest of native marine organisms. It is implicated in the decline of the critically endangered spotted handfish (*Brachionichthys hirsutus*) in Tasmania. It preys on handfish egg masses and/or on the sea squirts (ascidians) that handfish use to spawn on. The seastar is also considered to be a mariculture pest, settling on scallop longlines, spat bags, mussel and oyster lines and salmon cages. Oyster production on some marine farms in south-eastern Tasmania has been affected by the seastar (http://www. issg.org/database/species/ecology.asp?fr=1&si=82).

Another example is *Balanus improvisus*, which is a species of *acorn barnacle*. It is not known where the species' natural range lies, but it has recently colonized many parts of the world's oceans as a biofouling agent on the hulls of ships. It was one of the first recorded introductions to the Baltic Sea, having been found in Sweden and Lithuania in 1844, the Elbe estuary in 1854 and Great Britain in the 1880s. Settling of barnacles (*Balanus improvisus*) is shown in Fig. 5.29.

Consequences of these bioinvasions for human activities are illustrated by Photos 5.88–5.90.

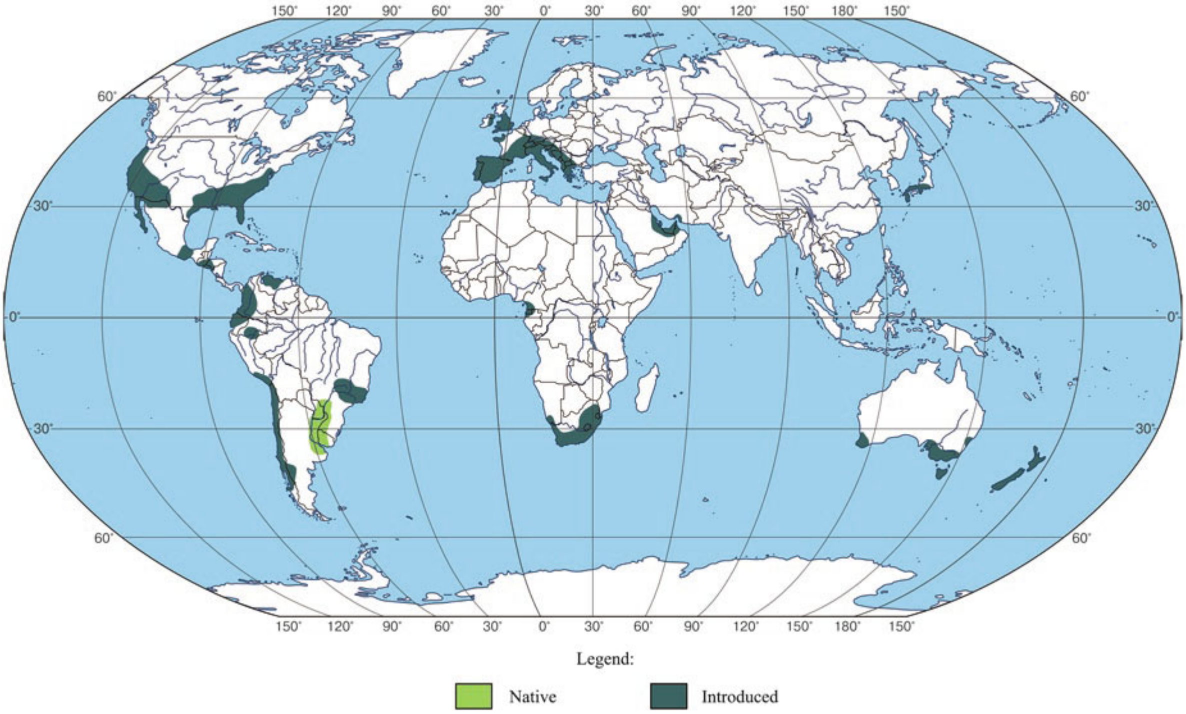

Fig. 5.30 Global distribution of Argentine ant (*Linepithema humile*) (http://scienceblogs.com/myrmecos/2008/04/how-to-identify-the-argentine-ant-linepithema-humile.php. Reproduced with permission of Dr. A. Wild)

5.11.5 Terrestrial Invertebrates

Insects represent most of the terrestrial invertebrate invaders. There are also some important *molluscs*. Insects can get into new habitats by themselves in natural ways: by active flight of adult insects and by drifting with the wind and ocean currents. However, most of the accountability for their relocation lies on the shoulders of mankind.

Anthropogenic insect bioinvasions can occur in the following *ways*: (1) planting materials (cuttings, tubers, rhizomes, bulbs, etc.); (2) fruits; (3) ornamental plants in pots, containers, etc.; (4) cut flowers; (5) seeds and products of their processing; (6) timber (under bark, in cracked wood); (7) soil, dirt and other substrates; (8) packaging and packing materials; (9) transport and (10) directly by people (Mironova and Izhevsky 2007).

In some regions, the *numbers of invaders* are very significant. For example, 1,300 species of insects were brought by people to the Hawaiian Islands out of a total of 5,000 species of insects recorded there (Dorst 1968).

There are five species of *ants* out of a list of 17 worst invasive terrestrial species of invertebrates, which in turn are included in the general list of the 100 worst invasive species. The global distribution of the Argentine ant (*Linepithema humile*) is shown in Fig. 5.30.

The *red imported fire ant* (*Solenopsis invicta*) is the most notorious. The native habitat of this little ant (2–6 mm) is South America. In 1930, a ship transported them from Brazil to the port of Mobile, Alabama (United States). Presumably, they were in ground ballast waters (Lockey 2007). Since then, they have spread to 14 US southern states. In a similar way, these ants were accidentally introduced into Australia in 2001 (McCubbin and Weiner 2002).

Red ants live mainly in urban areas; for example, in courtyards of private houses, on school grounds, or on roadsides. They damage *electrical insulation*, disabling *electric motors*, *pumps*, *telephone relays*, *fire systems*, *traffic lights*, *air conditioners* and other equipment (Davis and Grimm 2003).

Photo 5.91 The yellow fever mosquito (*Aedes aegypti*) originated in Africa but is now found in tropical and subtropical regions throughout the world. This species can spread the dengue fever, Chikungunya, and yellow fever viruses, as well as other disease agents. The photo shows *Aedes aegypti* feeding in Dar es Salaam, Tanzania (Photo credit: Muhammad Mahdi Karim, 2009)

Photo 5.92 The Asian long-horned beetle (*Anoplophora glabripennis*) probably travelled to the United States inside solid wood packing material from China, and the beetle has been intercepted at ports and found in warehouses throughout the United States. It has been found attacking trees and has been controlled at these locations (Photo credit: http://en.wikipedia.org/wiki/Asian_long-horned_beetle)

Photo 5.93 This regulatory notice, posted on Belfield Road in Toronto, Ontario, Canada, is part of the Canadian Food Inspection Agency's efforts to contain the current infestation of Asian long-horned beetles within the presently affected areas of the Greater Toronto Area (Photo credit: http://en.wikipedia.org/wiki/Asian_long-horned_beetle, 9 August 2008)

Photo 5.94 The gypsy moth (*Lymantria dispar*) was introduced into the United States in 1868 by a French scientist, Leopold Trouvelot, living in Medford, Massachusetts. The native silk-spinning caterpillars were proving to be susceptible to disease, so Trouvelot brought over gypsy moth eggs to try to make a caterpillar hybrid that could resist diseases. When some of the moths escaped from his lab, they found suitable habitat and started to multiply. The gypsy moth is now one of the most notorious pests of hardwood trees in the eastern United States. The photo shows a leaf eaten by a gypsy moth (Photo credit: Pennsylvania Department of Conservation and Natural Resources, Forestry Archive, Bugwood.org)

In the process of building their nests and mounds, these ants can break so much ground that they can cause problems for *roadways* and *retaining walls*. In agriculture, red imported fire ants cause damage to many species of *plants*; their activity in gardens often creates difficulties for workers collecting fruits. Numerous ant mounds (usually approximately 100 and sometimes 400/ha) interfere with hay-making and *transportation* on farmland.

Approximately, 33,000 people ask for *medical assistance* in the United States each year after being bitten by red imported fire ants; some cases are severe and require hospitalization. Death can occur in people with allergic reactions (Lockey 2007). Red imported fire ants cause US$3 billion of *losses* in the United States, annually (Davis and Grimm 2003).

The *East African land snail* (*Achatina fuliica*) is a harmful mollusc. It is a large snail; the shell reaches lengths of up to 13 cm and the body up to 20 cm. It spread from Ethiopia to Mozambique. It resides in trees, eating their shoots and buds. Within the limits of its original habitat, *Achatina* does not cause much harm.

However, wherever this species is brought by people to places outside of its native habitat, such as in tropical zones of the eastern hemisphere, this snail causes harm to *cultivated plants*, especially on tea, banana and rubber plantations. It has the ability of unusually rapid *reproduction*; the brood from a single specimen can reach eight billion in 3 years. These snails, in fact, cause *car accidents* on the Mariana Islands, as car tyres slip on the roads which are completely covered with crushed snails. In addition, *Achatina* carries on its foot various disease-causing bacteria to seeds and plants (Dorst 1968).

Economic losses associated with the introduction of insects alone are US$20 billion a year in the United States (Hoebeke 2003).

Consequences of these bioinvasions for human activities are illustrated by Photos 5.91–5.94.

Photo 5.95 The photo shows an unusually large Nile perch (*Lates niloticus*), netted along the White Nile in southern Sudan. Its introduction into Lake Victoria in 1954 had extremely adverse effects on local icthyofauna. Predation of Nile perch led to the destruction of 200 endemic fish species. At present, it makes up 80% of the lake fish mass (Photo credit: Sudan government, 1962. Presented by FAO, print 4849-1)

5.11.6 Fish and Cyclostomes

The *Nile perch* (*Lates niloticus*) is the most famous and dramatic invasive fish because of the infamous consequences of its introduction into Lake Victoria. This fish is widely distributed in tropical Africa, inhabiting the Congo, Nile, Niger and Senegal Rivers and some of the lakes: Chad, Volta, Rudolf and Albert.

Lake Victoria was one of the *richest lakes* in the world, based on the diversity of fish species, before the introduction of the Nile perch. In particular, there were over 400 haplochromine cichlid species, accounting for 5% of the world's known freshwater fish. Haplochromine species accounted for 83% of the fish biomass in the lake (Cophen et al. 1995).

The Nile perch was *transported* there in 1954 from Lake Albert (Ogutu-Ohwayo 2004). At first, the environmental effects were minor. However, a *dramatic surge* in the Nile perch population took place in the 1980s. Predation by the Nile perch led to the *destruction* of 200 endemic fish species.

The introduction of Nile perch had *additional ecological effects* onshore. Native cichlids were traditionally sun-dried fish, but Nile perch has a higher fat content than cichlids, so instead, it needed to be smoked to avoid spoilage. This led to an increased demand for firewood in a region already hard-hit by deforestation, soil erosion and desertification (http://en.wikipedia.org/wiki/Nile_perch).

The origin of the *common carp* (*Cyprinus carpio*) remains unclear. According to some data, it came from

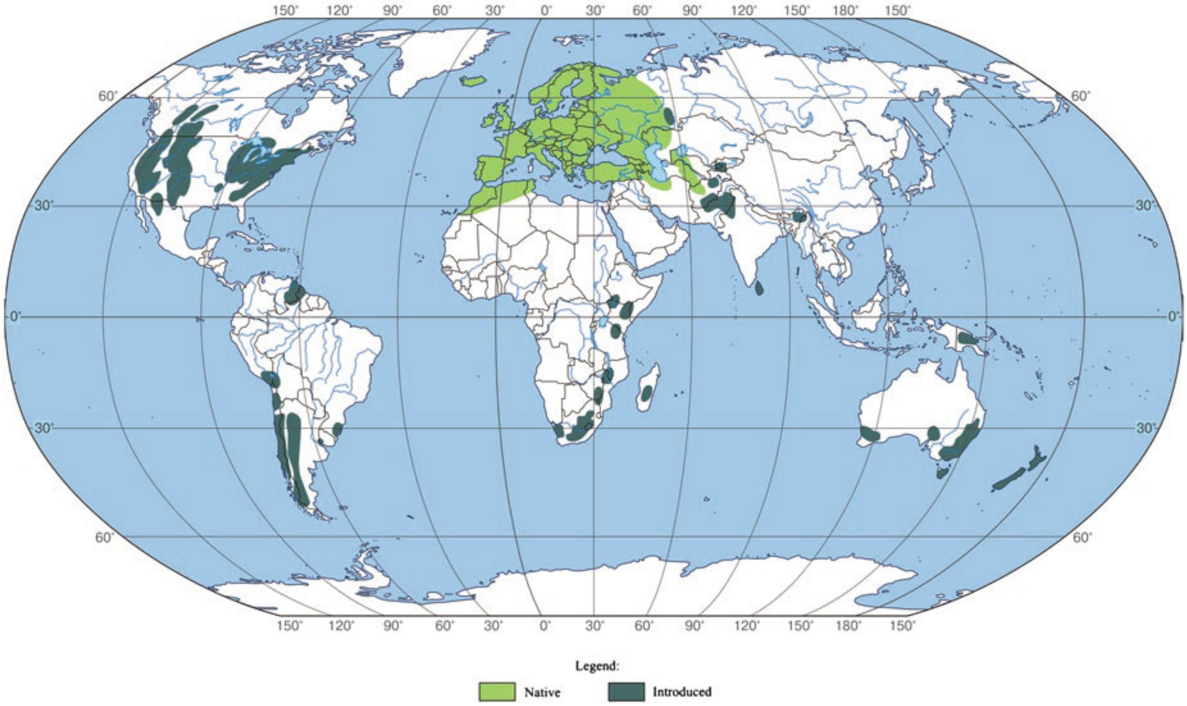

Fig. 5.31 Global distribution of brown trout (*Salmo trutta*) (Adapted from Goudie (1997), Elliott (1994))

Asia (http://www.issg.org/database/species/ecology.asp? si = 60fr = 1&sts = sss); according to other sources, its birthplace was in Europe (http://en.wikipedia.org/wiki/Common_carp). This fish can reach 1.2 m in length and weigh up to 60 kg. Carp can survive temperatures from 4°C to 35°C, salinity up to 14‰, almost the upper limits of pH, and polluted, poorly oxygenated water (http://www.daff.gov.au/__data/assets/word_doc/0013/91102/ carp_factsheet.doc).

The common carp was introduced by people, sometimes illegally, all over the world. In some regions, delivery was justified, but in others, its introduction has led to *undesirable* consequences. It was introduced into 140 countries, at least, and significant negative consequences have been recorded in 18 states of the world (http://www.issg.org/database/species/ecology.asp?si=60fr=1&sts=sss).

In 1876, 345 carp fingerlings were brought into the *United States*, and they were grown in fish farms and distributed throughout the country. They multiplied extremely fast, and their numbers began to increase further due to replacement of native fish, which were more valuable economically. The replacement took place due to the tolerance of carp to habitat conditions and better utilization of forage resources (Dorst 1968).

It was soon discovered that carp cause changes in the environment, *destroying aquatic vegetation.* Sometimes, they pull plants out by their roots, increasing *turbidity* and, thereby, reducing the amount of light available for photosynthesis. Some waters were completely devoid of vegetation. In addition, carp actively eat the *eggs of other fish*. Once carp became adapted and widespread in a watershed, they became difficult to destroy (http://nas.er.usgs.gov/fishes/accounts/cyprinid/cy_carpi.html). Now, the common carp is found in all US states except Alaska (http://www.csa.com/hottopics/ern/99nov/biodv-26f.html).

Australia is also among the countries where the introduction of carp has had undesirable consequences. This fish was often released into natural water bodies in the 1800s and 1900s, but the actual mass reproduction of carp occurred after its release into the Murray River from a fish farm near the town of Mildura. This release coincided with an extensive flood in 1970, which enabled carp to widely inhabit the basins of the Murray and Darling Rivers.

A survey of the rivers in *New South Wales* found that in some rivers, carp represented over 90% of the fish *biomass,* and the density of its population was 1 specimen per square metre of water surface. Studies also have shown that due to increased turbidity, the recreational value of these areas has decreased (http://www.daff.gov.au/_data/assets/word_doc/0013/91102/carp_factsheet.doc).

Similar problems also have been noted in *South Africa* and Brazil. For example, in the Iguazu River in south-eastern Brazil, the carp has displaced many commercially important fish species (Dorst 1968).

The *brown trout* (*Salmo trutta*) is normally considered to be native to Europe and Asia. The species has been widely introduced for purposes of sport into North America, South America, Australia, New Zealand and many other countries. The first planting in the United States occurred on 11 April 1884, into the Baldwin River, 1 mile east of Baldwin, Michigan. Brown trout have had serious negative impacts on upland native fish species in some of the countries where they have been introduced, particularly Australia (http://en.wikipedia.org/wiki/Brown_trout). The global distribution of brown trout is shown in Fig. 5.31.

The *sea lamprey* (*Petromyzon marinus*) is an example of the introduction of cyclostomes. This parasitic lamprey inhabits the Atlantic coasts of Europe and North America, as well as the western Mediterranean. It can grow up to 90 cm long. The lamprey uses its suction-cup-like mouth to attach itself to the skin of fish, and it rasps away tissue with its sharp, probing tongue and teeth. Secretions in the lamprey's mouth prevent the victim's blood from clotting. Victims typically die from excessive blood loss or infection (http://en.wikipedia.org/wiki/Sea_lamprey).

The lamprey spends most of its life in seas, but it migrates systematically to rivers, where it spawns. The lamprey came into *Lake Ontario* in 1825 (http://www.csa.com?hottopics/ern/99nov/ biodv-26f.html), but it could not go farther because of Niagara Falls.

However, after the *Welland Canal* was built in 1919 to allow boats to bypass Niagara Falls, lamprey entered *Lake Erie* in 1921, *Lake Michigan* in1936, *Lake Huron* in 1937 and, finally, the eastern part of *Lake Superior* in 1946 (Dorst 1968).

Photo 5.96 The sea lamprey (*Petromyzon marinus*) inhabits the Atlantic coasts of Europe and North America, as well as the western Mediterranean. It uses its suction-cup-like mouth to attach itself to the skin of fish, and it rasps away tissue with its sharp, probing tongue and teeth. Secretions in the lamprey's mouth prevent the victim's blood from clotting. The photo shows the mouths of adult and juvenile sea lampreys (Photo credit: Michigan Sea Grant)

Further spread of the lamprey was '*explosive*'. They began to multiply rapidly in the rivers flowing into the Great Lakes and to cause damage to local ichthyofauna. The numbers of commercial fish – *lake trout* (*Salvelinus namaycush*) and *lake whitefish* (*Coregonus clupeaformis*) – dropped catastrophically, and the overall productivity of Lakes Huron and Michigan fell from 8.6 million lake trout to 26,000 (Dorst 1968). When populations of lamprey were the highest, 85% of the fish caught showed lamprey-inflicted wounds (http://www.

Photo 5.97 The lamprey came into Lake Ontario in 1825, but it could not go farther because of Niagara Falls. However, after the Welland Canal was built, the lamprey entered Lake Erie in 1921, Lake Michigan in1936, Lake Huron in 1937, and, finally, the eastern part of Lake Superior in 1946. Lampreys cause damage to local ichthyofauna. Victims typically die from excessive blood loss or infection. Only about 10% of fish survive after attacks by lampreys. Sea lampreys on lake trout are shown here (Photo credit: US Fish and Wildlife Service)

glsc.gov/information/factsheets/sea_lamprey00/sea_lamprey00.htm).

Consequences of these bioinvasions for human activities are illustrated by Photos 5.95–5.97.

5.11.7 Amphibians and Reptiles

The *cane/marine toad* (*Bufo marinus*) is a large toad. The length of its body can reach 24 cm (usually 15–17 cm), and it can weigh over a kilogram. The *natural habitat* of the cane toad stretches from the Rio Grande in Texas to central Amazonia and north-eastern Peru. This toad was introduced into several regions of the world for pest control. All introductions have been well documented, so the cane toad is one of the *most studied* of introduced species.

The cane toad was introduced into *Martinique* and *Barbados* from French Guiana and Guyana in the early 1840s. It was introduced into *Jamaica* in 1844 in an attempt to reduce local rat populations. Despite its failure to control the rodents in Jamaica, the cane toad was introduced into *Puerto Rico* in the early twentieth century, in the hope that it would counter a beetle infestation that was ravaging sugar cane plantations. The Puerto Rican scheme was successful, and the toad halted economic damage caused by the beetles, prompting scientists in the 1930s to promote it as an ideal solution to agricultural pests (http://en.wikipedia.org/wiki/Cane_toad).

After this, the cane toad was brought specifically to combat pests on the east coast of *Australia*, south *Florida, Papua New Guinea,* the *Philippines*, the Japanese island of *Ogasawara*, the *Ryukyu Islands*, and to many *Caribbean* and *Pacific islands*, including *Hawaii* (in 1935) and *Fiji*.

In June 1935, 101 toads were transported to *Edmonton* (North Queensland, Australia) from Hawaii for fighting two pests of sugar cane: French's cane beetle and the greyback cane beetle. In captivity, they managed to procreate, and approximately 3,400 young toads were released on a plantation in northern Queensland in July 1935 (http://www.austmus.gov.au/factsheets/canetoad.htm).

The cane toad proved *ineffective* against the pests because it found another prey, but the toads quickly began to increase their populations and spread. They reached the border of New South Wales in 1978 and

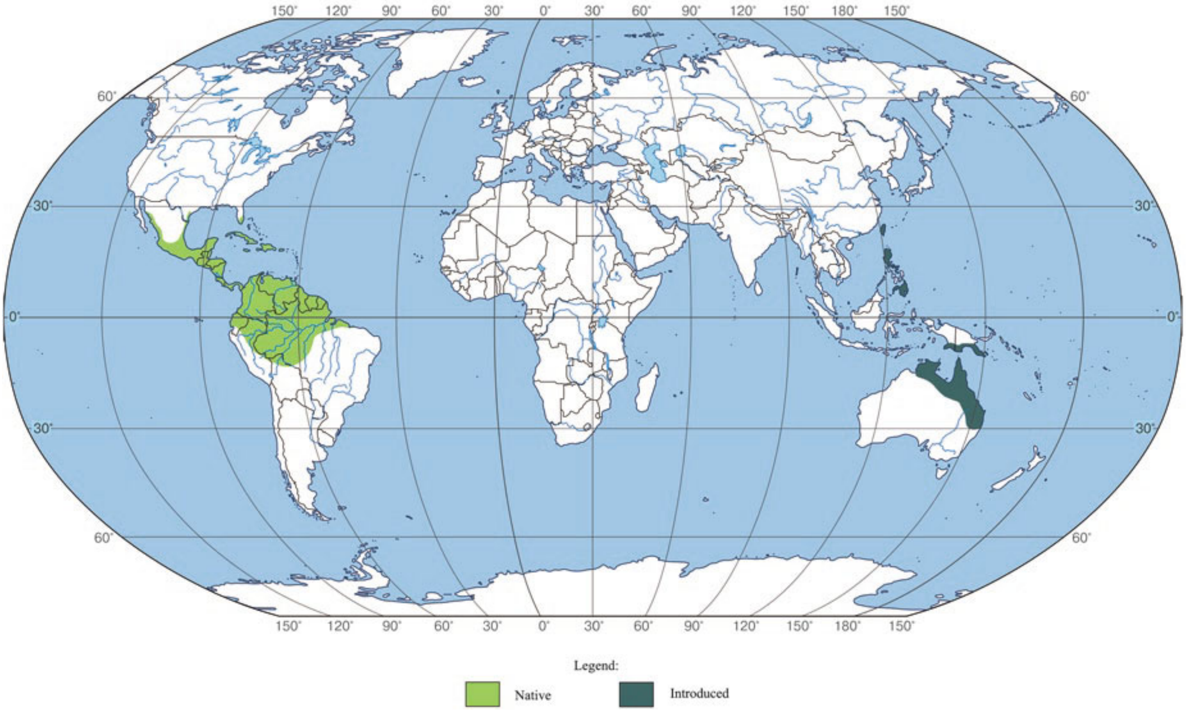

Fig. 5.32 Global distribution of the canc toad (*Bufo marinus*) (http://www.iucnredlist.org/apps/redlist/details/41065/0. Reproduced with permission of International Union of conservation of Nature)

the Northern Territory in 1984. At this time, the range of this species *continues to grow* in Australia. The boundary of their settlement moves by 30–50 km/year in the Northern Territory and by 5 km/year in the northern part of New South Wales (http://www.jcu.edu.au/school/PHTM/staff/rsbufo.htm). The present global distribution of the cane toad (*Bufo marinus*) is shown in Fig. 5.32.

Cane toads are considered to be *pests* in Australia *because they* (1) poison pets and injure humans with their toxins, (2) poison many native animals whose diet includes frogs, tadpoles and frogs' eggs, (3) eat large numbers of honeybees, creating a management problem for beekeepers, (4) prey on native fauna, (5) compete for food with vertebrate insectivores such as small skinks and (6) may carry diseases that can be transmitted to native frogs and fish (http://australianmuseum.net.au/Cane-Toad).

Initially, the *brown tree snake* (*Boiga irregularis*) lived in Australia, Indonesia, Papua New Guinea and the Solomon Islands. Shortly after the Second World War, the brown tree snake appeared on the island of

Photo 5.98 The cane toad is native to the Americas, and its range stretches from the Rio Grande valley in southern Texas to the central Amazon and south-eastern Peru. The cane toad has been introduced to many regions of the world for the biological control of agricultural pests. It has become a pest in many host countries, and it poses a serious threat to native animals. The photo shows a specimen of *Bufo marinus* from El Salvador (Photo credit: Eli Greenbaum)

Photo 5.99 The brown tree snake was accidentally transported to Guam, probably as a stowaway in ship cargo. As a result of abundant prey resources on Guam and the absence of natural predators, brown tree snake populations reached unprecedented numbers. Snakes caused the extirpation of most of the native forest vertebrate species; thousands of power outages affecting private, commercial and military activities; and widespread loss of domestic birds and pets. The photo shows a brown tree snake on a fence post in Guam (Photo credit: Mark Kempen, 2003)

Guam (the largest of the Mariana Islands in the western Pacific). How it got there is unclear. According to some data, it was brought to Guam on a cargo vessel (http://en.wikipedia.org/wiki/Brown_tree_snake); according to other data, it was brought by a military plane (www.issg.org/booklet.pdf).

The snake bred there in huge numbers because of a lack of local enemies. Its presence there led to the *extinction* of 9 out of 13 species of *forest birds* and half of the species of *reptiles* that lived on the island (Mitchell 2001). There were also cases of humans being bitten.

The brown tree snake greatly complicates the *electric supply* there. It climbs on power poles, anchor lines and transformers, often causing electric short circuits. More than 1,600 power outages were recorded on the island due to brown tree snakes in 1978–1997. All these complicates many other activities, such as trade, banking, air transportation and medical care (http://www.mesc/usgs.gov/ resources/education/bts/impacts/electrical.asp). Economic *damage* from the brown tree snake on Guam is estimated at US$1–4 million per year (http://www.mesc/usgs.gov/resources/education/bts/impacts/economic.asp).

Consequences of these bioinvasions for human activities are illustrated by Photos 5.98 and 5.99.

5.11.8 Birds

A striking example of the negative effects of an invasive bird is the introduction of the *European starling* (*Sturnus vulgaris*). This bird came from southern and western Europe and North Africa; however, it was introduced to *Australia* (1857), *New Zealand* (1862), *North America* (1890) and *South Africa* (1890). The European starling is among the most familiar birds in temperate regions. It is 19–22 cm long, with wingspans of 37–42 cm and weighs 60–90 g (http://en.wikipedia.org/wiki/European_Starling).

The introduction of the starling into the *United States* is informative. In the late nineteenth century, homesick European immigrants were keen on settling familiar birds around their new residences. One enthusiast, a lover of Shakespeare, decided to introduce into the United States all the birds mentioned in the writer's works. One of the birds was mentioned only once – the European starling. In 1890, several pairs of these birds

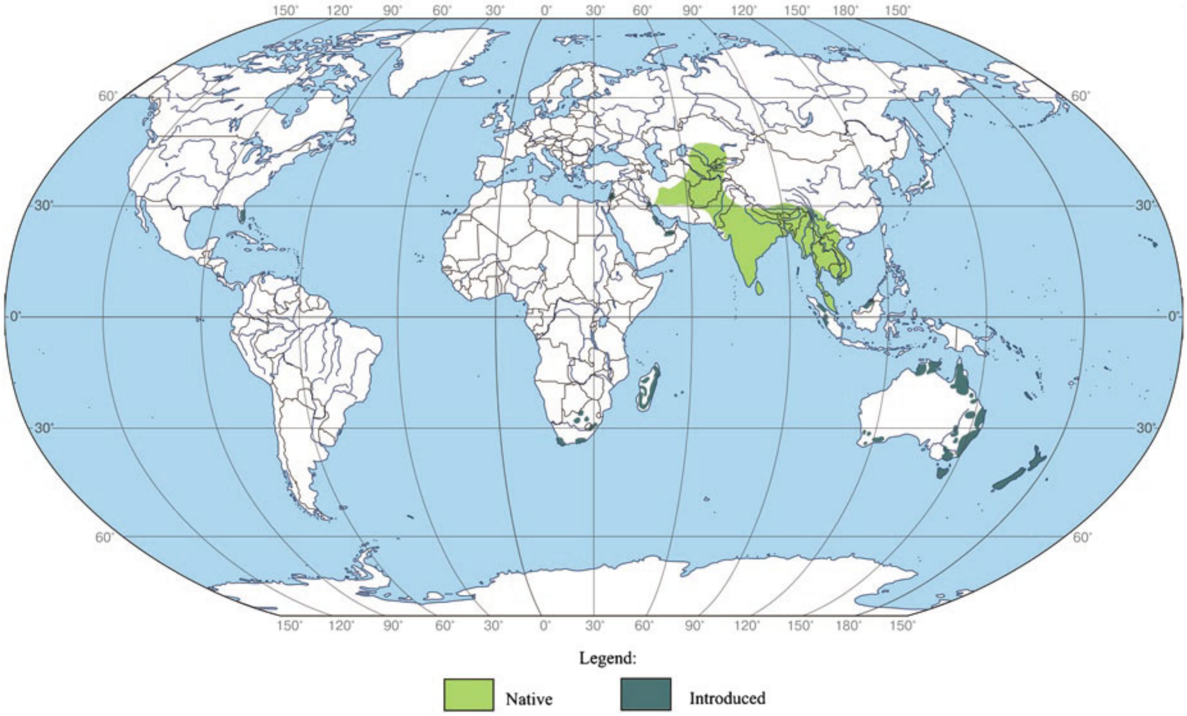

Fig. 5.33 Global distribution of the common myna (*Acridotheres tristis*) (http://en.wikipedia.org/wiki/File:Common_Mynah_distribution_map.png)

were released in Central Park in New York City (http://iimk.ac.in/gsdl/cgi-bin/library).

Now it is one of the most numerous birds there. Its range extends from the western to the eastern coast and from Alaska to southern Mexico. Large populations of starlings cause serious damage to *agriculture*. They damage such fruits and berries as grapes, peaches, blueberries, strawberries, figs, apples and cherries. Starlings contaminate *livestock* feed and stored *grain* in granaries with their droppings. They also cause damage to corn plantations, and they eat the *sprouts of vegetables* and *flowering plants* (http://www.gsmfc.org/nis/nis/Sturnus _vulgaris.html).

Their *droppings* create a lot of problems. They contain uric acid, which damages automobile finishes and spoils their appearance. Starlings inhabit warehouses and defaecate on goods stored there, contaminating them. *Annual losses* from pollution by faeces of private property is measured in millions of dollars (http://en.wikipedia.org/wiki/European_Starling).

Starlings may also be responsible for *transferring disease* from one livestock facility to another. This is of particular concern to swine producers. Tests show that the transmissible gastroenteritis virus (TGE) can pass through the digestive tract of a starling and be infectious in the starling faeces (http://icwdm.org/handbook/birds/EuropeanStarlings.asp).

Large flocks of starlings that live near airports threaten *aviation security*. They can be sucked into jet engines, resulting in aircraft damage or loss and, at times, in human injuries. There is one, authentically known, case when starlings were to blame for an airplane crash that killed 62 people (Sect. 5.12.4.1).

Starlings also compete with *native cavity-nesting birds* such as bluebirds, flickers and other woodpeckers, purple martins and wood ducks for nest sites. One report showed that, where nest cavities were limited, starlings had severe impacts on local populations of native cavity-nesting species (http://icwdm.org/handbook/birds/ EuropeanStarlings.asp).

The *common myna,* or *Indian myna* (*Acridotheres tristis*), comes from Asia. It has been introduced in several areas of the world and is now one of three bird species included in the list of the 100 worst invasive species of the world. The global distribution of the common myna is shown in Fig. 5.33. The most serious problem this bird created is in Australia.

Photo 5.100 The common myna (*Acridotheres tristis*) has been introduced in many other parts of the world, and its distribution range has increased to the extent that in 2000 the IUCN Species Survival Commission declared it among the world's 100 worst invasive species. The myna is one of only three birds on this list of invasive species. It is a serious threat to the ecosystems of Australia. A common myna in Sydney Park, Alexandria, Sydney, Australia, is shown here (Photo credit: Richard Taylor (Australia), 12 May 2010)

Photo 5.101 The European starling (*Sturnus vulgaris*) was introduced into the United States in 1890. Now it is one of the most numerous birds there. They create flocks reaching up to 1.5 million birds and cause problems with their droppings. These may accumulate up to 30 cm deep, killing trees due to their concentrated chemicals. The photo shows a flock of starlings in Napa Valley, California (United States) (Photo credit: Mila Zinkova, 2009. This file is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license. http://commons.wikimedia.org/w/index.php?title=File:Sturnus_vulgaris_in_Napa_Valley_1.jpg&oldid=43515269)

The common myna was introduced into *Australia,* at first in Victoria, between 1863 and 1872 into Melbourne's market gardens to control insects. The bird is likely to have spread to New South Wales (where it is currently most populous) at around the same time, but documentation is uncertain. The bird was later introduced into Queensland as a predator of grasshoppers and cane beetles (http://en.wikipedia.org/wiki/Common_Myna).

The bird has created a number of *economic problems* in many parts of Australia, causing damage to fruit trees and crops. In addition, their *noise* and *odour* annoy residents of the suburbs. However, the most serious impact of this bird, for which it is called the flying cane toad, is a *decline in biodiversity.*

The common myna is a very *aggressive* bird. It nests in hollow trees, which are not plentiful in most of Australia. Common mynas reduce biodiversity by fighting for hollows with birds like rosellas, destroying their eggs and chicks and, thus, preventing them from developing. They also evict small mammals like sugar glider marsupials (*Petaurus breviceps*) from hollows, which commonly means a death sentence for the gliders (http://sres.anu.edu.au/ associated/myna/intro.html).

Consequences of these bioinvasions for human activities are illustrated by Photos 5.100 and 5.101.

5.11.9 Mammals

Fourteen mammals are included among the 100 worst invasive species. Everyone knows the disastrous consequences of the introduction of *rabbits* into Australia or *goats* on the island of St. Helena. The global distribution of the wild rabbit is shown in Fig. 5.34.

However, in terms of economic damage, nothing can compare with the expansion of *rats*: the black rat (*Rattus rattus*) and the brown rat (*Rattus norvegicus*). The vast majority of mammals were introduced by people deliberately; rats, by exception, became globally widespread, being unwittingly assisted by humans.

The *brown rat* (*Rattus norvegicus*) is known by many names: *common rat, sewer rat, Hanover rat, Norway rat, brown Norway rat, Norwegian rat, or wharf rat*. Being originally from the plains of northern China and Mongolia, it is now common on all continents (except Antarctica). Brown rats partially settled along waterways on their own, but most moves

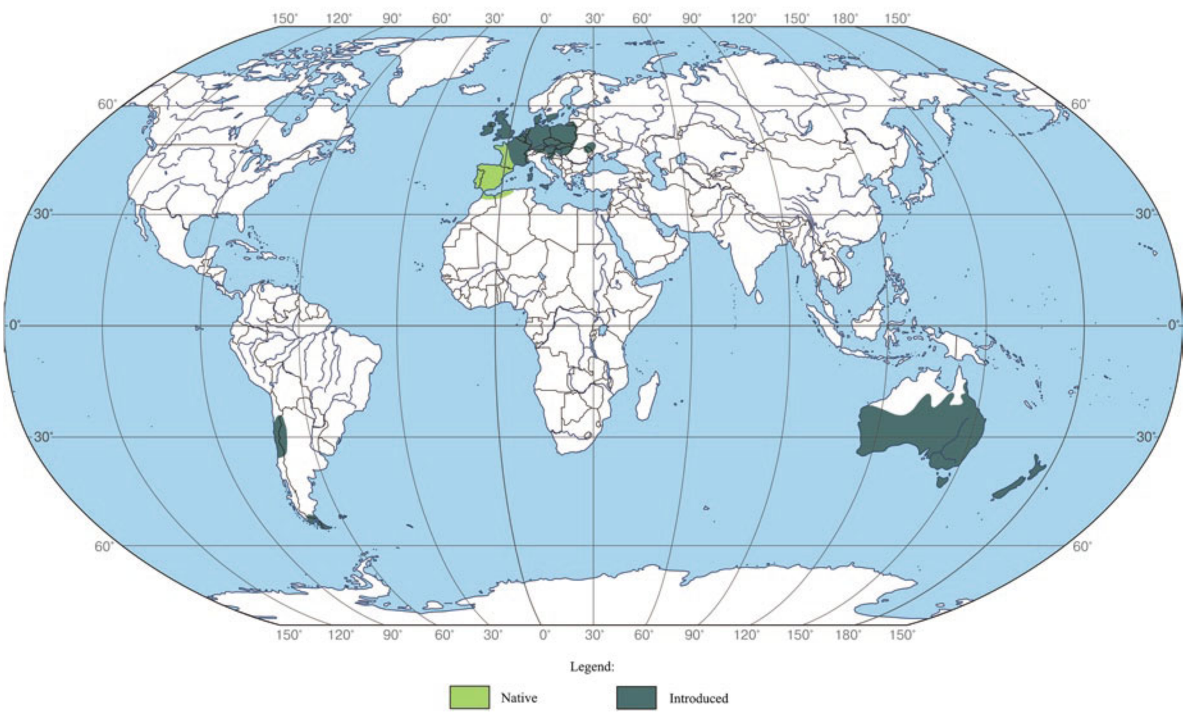

Fig. 5.34 Global distribution of wild rabbit (Reproduced with permission of International Union for conservation of Nature)

were assisted by humans. Movements are mainly on *river* and *marine boats* rather than by other modes of transportation (rail, road and air). Subways are an exception. Rats settle and live in subways in huge numbers (http://en. wikipedia.org/wiki/Brown_rat).

Rats settle with great speed after they first enter a city. Thus, the settlement of rats in *Barnaul* (Russia) was traced precisely to the early twentieth century. During the *first* year, they appeared and lived only in pier structures and buildings; during the *second* year, they took quarters near the pier; the *third* year, they reached the city centre; in the *fourth* year, they occupied the whole city and in the *fifth* year, rats began to settle in the suburbs. Rats penetrated structures through *open doors* (especially at night) and through *vents* in basements and first floors.

It is believed that the *rat population* is double the number of people on Earth. In the *United States*, there are approximately 1.25 billion black rats (Mitchell 2001). In the *United Kingdom*, the population of brown rats was estimated at 60 million in 2003 (http://en.wikipedia. org/wiki/Brown_rat).

Damage caused by rats is huge (spoilage of food, materials and appliances; damage to cable insulation, leading to short circuits; spread of infections, etc.). Information on this is presented in relevant sections of the book. Also, the enormous damage caused by rats to biodiversity is worth noting.

Perhaps the most damage by rats was caused to the fauna and flora of *New Zealand*. Rats appeared in this country approximately 160 years ago. They have a major impact on New Zealand's wildlife because they eat birds, their eggs, chicks, lizards and invertebrates (beetles, spiders, wetas and flies). They also eat a wide range of native fruits and plant parts, which puts them in competition with native wildlife for food. The *black rat* (*Rattus rattus*) is generally a greater threat to forest birds because of its *climbing ability*. However, the black rat also feeds on ground-nesting birds and their youngsters, especially those that nest close to waterways.

Rats have inflicted the greatest damage to bird populations; namely, the *grey-faced petrels* (*Pterodroma macroptera gouldi*), the near-threatened *saddlebacks/tiekes* (*Philesturnus carunculatus*) and the endangered *kaka* (*Nestor meridionalis septentrionalis*), as well as flightless *weevil* species (*Hadramphus stilbocarpa and Anagotus fairhurni*) and others (Innes 2001).

Photo 5.102 A brown rat (*Rattus norvegicus*) attacking an adult fantail brooding 8-day-old chicks at night is shown. Brown rats invaded New Zealand about 160 years ago, and since then, they have damaged fauna of the country severely, eating up birds and invertebrates, including beetles, butterflies, and spiders. The population of tomtits, thrushes, parrots, huias and petrels on the neighbouring islands suffer from brown rats to the greatest extent (Photo credit: David Mudge, January 1998)

Photo 5.103 As to wild animals introduced into Australia, rabbits do the maximum damage to the environment. In particular, rabbits are responsible for serious erosion problems, as they eat native plants, leaving the topsoil exposed and vulnerable to sheet, gully and wind erosion. The removal of this topsoil is devastating to the land, as it takes many hundreds of years to regenerate. Erosion of a gully in South Australia caused by rabbits is shown here (Photo credit: http://en.wikipedia.org/wiki/Rabbits_in_Australia)

Photo 5.104 Nutria (*Myocastor coypus*), originally native to temperate South America, has since been introduced to North America, Europe, Asia and Africa, primarily by fur ranchers. Although it is still valued for its fur in some regions, its destructive feeding and burrowing behaviours make this invasive species a pest throughout most of its range. The photo shows nutria with little ducks in Germany (Photo credit: J. Patrick Fischer, July 2007)

The *small Indian mongoose* (*Herpestes javanicus*) is also known as the small Asian mongoose, Indian mongoose, or Javan mongoose. The natural habitat of this predator is Asia, from Iran, through India, to Myanmar and the Malay peninsula. It was introduced to various parts of the globe, in many cases, with the motive of controlling rats (www.issg.org/booklet.pdf).

In *Jamaica*, rats destroyed approximately 20% of the sugar cane crop. Four males and five female mongooses were brought from *Calcutta* to fight them in 1872 (Simberloff et al. 2000). These animals quickly multiplied on the island and drastically reduced the number of rats. After that, the mongoose settled on many other islands in the *West Indies*.

However, the mongooses began destroying various *native animals* also, particularly ones that were easier prey: birds that nest on the ground, as well as lizards, frogs and land crabs. They began to hunt pigs, lambs, guinea pigs and other animals. It is believed that the mongoose *eliminated* more species of Antilles animals than those eliminated by people on the entire North American continent (Revyako 1998).

Consequences of these bioinvasions for human activities are illustrated by Photos 5.102–5.104.

5.12 Biodeterioration

Biodeterioration is a change in the characteristics of anthropogenic materials or natural materials used as raw materials due to the activities and presence of living organisms.

The problem of biodeterioration is extremely widespread. It is caused by the need to protect materials and technical equipment from damage caused by bacteria, fungi, plants, worms, molluscs, insects, birds and mammals – in terms of their exploitation, transportation and long-term storage. *Damage* from biodeterioration ranges, based on different data, from 2%) to 5% (Stepanyan 1996) of industrial product value. Total damage from biodeterioration is US$50 billion a year, according to S.M. Myagkov (1995).

In many cases, damage from biodegradation is *impossible to estimate* in monetary terms, such as damage to cultural sites and archival documents, or death of passengers and crews in aircraft collisions with birds. *Many industries* are interested in solving this problem; for example, all types of transportation, the chemical industry, construction, communications, energy, oil and the petrochemical industry and agriculture.

Biodeterioration can be divided into the following basic *groups*: (1) destruction of products in contact with large organisms, (2) deterioration of operational properties, (3) biochemical destruction of work materials, and (4) physico-chemical corrosion where materials and organisms interact (Tsukerman 1983).

The *first* group includes destruction inflicted by large organisms. These include (1) physical contact of animals with vehicles (e.g. birds with aircraft); (2) damage unrelated to feeding (e.g. gnawing of holes by rodents) and (3) feeding by rodents, maggots, termites and other organisms.

The *second* group includes (1) fouling (ships, water pipes, fixed structures and machinery components) and (2) formation of mucus films and clots in oil and fuel as a result of bacterial activity. The effects of this group do not lead to deterioration of structural materials but, instead, affect the functioning of technical systems. For example, fouling worsens the hydrodynamic properties of surfaces, capacity of culverts, mobility of joints and so on. In addition, bacterial films in fuel and clusters of mucus lead to clogged nozzles.

The *third* group is represented by damage that is caused by microorganisms. Damage can be caused by a release of chemicals (e.g. destruction of metals by acids formed by sulphate-reducing bacteria) and biological consumption of structural material (e.g. textile damage by moth larvae). The *fourth* group includes corrosion of metals under the action of microorganisms (by amino and organic acids, as well as by products of hydrolysis).

The problem of classifying biodeterioration is extremely difficult for the following *reasons*: (1) large number of biodeteriorating organisms; (2) significant numbers of biovulnerable objects, which are continuously increasing due to emergence of new materials and products and (3) the diversity of natural environments where biodeterioration occurs (air, water, soil and sediments).

Economic costs with regard to biodeterioration may include the costs of prevention, replacement, remedial measures and sometimes litigation.

Agents that cause biodeterioration are discussed in the following sections.

5.12.1 Bacteria and Fungi

Bacteria are a group of microscopic, mostly single-celled organisms. *Fungi* are a group of lower plants, lacking chlorophyll and feeding on organic matter.

These organisms cause the following *types* of damage, depending on their mechanism (Protection against corrosion, ageing and Ilyichev et al. 1987, vol 2): (1) mechanical, as a result of penetration of hyphae (microscopic branching filaments that form the fungus vegetative body), (2) formation of coats or films, (3) chemical effects and (4) specific changes in properties of the substrate.

In accordance with the nature of changes in material properties, biodeterioration can be classified as *follows* (Ilyichev et al. 1987): (1) changes in physical and mechanical properties (reduction of strength of wood and plastic, swelling of rubber, loss of coating adhesion), (2) deterioration of electrical properties, such as reduction in the insulating properties of materials, (3) changes in optical properties, such as reduction in the transparency of glass in optical equipment, etched by fungal metabolites, (4) changes in chemical properties of materials (oxidation or hydrolysis of plasticizers in plastics and of cellulose in wood) and (5) changes in organoleptic properties (development of odour in decaying grease or coolant, the appearance of mucus on solid surfaces, etc.).

Among the most susceptible materials and products are the *following*: (1) plastics, (2) rubber, (3) coatings, (4) fuels and lubricants, (5) metals and metallic structures, (6) timber, (7) paper and books, (8) textile fibres and materials, (9) leather, (10) building materials and glass and (11) complex technical products.

Damage to *plastics* is due to proliferation of fungal colonies on the surface of the product and penetration of mycelium into a material through micro-cracks, as well as a result of aggressive impact of metabolites (enzymes and organic acids) of fungi on separate components of plastics. Bacterial damage to plastic is quite rare. Their impacts on plastics lead to changes in colour, strength, electrical and other properties; deterioration of performance and product quality and loss of practical value (Ilyichev et al. 1987).

As for *technical-rubber products*, the most dangerous damage is to rubber gaskets and seals in pipes and loss of integrity in electrical insulation, leading to failure of transformers, electric motors, dynamos and other devices.

Damage to *paint coatings* is typical for buildings and premises with high humidity and temperatures (e.g. animal farms, swimming pools, saunas, meat and dairy companies and canning facilities). The main destroyers of the coatings are fungi that create the appearance of grey–green, brown, dark and other coloured spots and mildew attacks. Damage caused by bacteria is less common; it is characterized by the appearance of colourless or coloured mucus plaques.

Microbiological contamination of *fuels* and oils of petroleum origin is a serious problem for air transport. The best-known organism that causes degradation of fuel is the so-called '*kerosene fungus*' (*Cladosporium resinae*), which has caused a number of airline accidents. Growth of this fungus creates a mucilaginous emulsion, clogging fuel filters and impairing engines. Various kinds of marine and automotive fuel can be also affected by fungi and bacteria.

Biodamage of *metals* is commonly called *biocorrosion*. Over 50% of corrosive damage to metals is caused by microbial action (Protection against corrosion, ageing and biodeterioration 1987, vol 1). According to S.M. Myagkov (1995), biocorrosion of pipelines causes direct annual losses of US$2 billion in the United States alone. Most biocorrosion is caused by microscopic fungi and some *lithotrophic bacteria*: (1) sulphate-reducing bacteria, (2) thiobacteria (oxidize sulphur and its compounds to sulphuric acid) and (3) iron bacteria (oxidize ferrous iron to ferric iron).

The processes of biodegradation of *wood* are caused by fungi. Bacteria have an indirect damaging effect and cause less damage. In temperate latitudes, fungi are responsible for 90% of wood biodegradation (Ilyichev et al. 1987).

Biodeterioration of wood is caused by three main *groups* of fungi: (1) mould (form a coating mostly on old logs and sawn timber, affecting only the surface), (2) wood staining (affect lumber, wood packaging and structures; it stains wood in different colours, e.g. blue, yellow, orange and brown – deeply penetrating into the sap of the wood) and (3) wood-destroying fungi (damage living wood, damp wood materials and products from them, destroying the cells of the wood).

Wood-destroying fungi are the most dangerous. The *most significant* of them are stalkless Paxillus (*Paxillus panuoides*), dry rot fungus (*Serpula lacry-*

Photo 5.105 In temperate latitudes, fungi are responsible for 90% of wood biodegradation. They destroy woody tissue when its components (cellulose, lignin, etc.) are used for food. This results in a sharp reduction in wood strength. Decay caused by fungi is shown (Photo credit: Clemson University, USDA Cooperative Extension Slide Series, Bugwood.org)

mans), white fungus (*Coriolus vaporarius)*, wet rot fungus (*Antrodia vaillantii*, *Coniophora puteana, C. cerebella* and *Phellinus contiguous*), bracket fungus (*Fomitopsis rosea*) and others (Ilyichev et al. 1987; Protection against corrosion, ageing and biodeterioration 1987, vol 2).

Biodeterioration of *papers* and *books* is caused mainly by fungi. Fungal enzymes destroy the fibre of paper and some elements of paper products (e.g. glue, wax, paraffin, paint and starch). In textiles, the most damage occurs in natural fabrics (linen, cotton, etc.). Synthetic fibres and synthetic fabrics are *more biostable*. Biodamage affects primarily materials stored and used in *outdoor conditions*; for example, canvas, tents, tarpaulins, sails, fishing nets, ropes and packing materials. The *damage is recognized* as reduced mechanical strength, loss of weight, stained appearance and odours.

The main agents that cause *leather* to deteriorate are fungi that lead to deterioration of consumptive and performance properties of leather products.

The impacts of bacteria and fungi on *building materials* (concrete, stone, brick, binding materials, etc.) depend on their properties, such as construction and operating conditions. Under otherwise equal conditions, the risk of biodegradation increases at high temperatures and humidity. Thiobacteria, nitrifying bacteria and sulphate-reducing bacteria, as well as some types of fungi, are the main biological agents that degrade building materials, affecting their mechanical strength and appearance.

Some fungi (families Phycomycetes, Ascomycetes and Fungi Imperfecti) can damage *glasses* and *optical systems* (http://www.mypentax.com/Fungus.html). They can grow on substrates that do not contain moisture and in conditions of low humidity. With their growing mycelium, they cover the surfaces of optical components, and they also can destroy glass surfaces with their metabolic products. This leads to a sharp decrease in the optical properties of lenses.

Microscopic fungi cause the most damage to *sophisticated equipment*. Such equipment is composed of various materials. Polymers, metals, enamels, paints, coatings, adhesives and lubricants are among the most vulnerable materials. Insulating materials, power sockets, circuit boards and other modules are affected the most. An estimated 0.5% of failures of electronic equipment are associated with biodeterioration by microorganisms (Protection against corrosion, ageing and biodeterioration 1987, vol 2).

Losses due to biodeterioration activity of bacteria and fungi are very significant. Fungal damage was colossal to armies of different countries in tropical regions during the Second World War. For example, the Australian army experienced considerable losses of property in New Guinea: 100,000 pairs of shoes, clothes, tarpaulins, tents, rubber products, electrical equipment, binoculars, cameras and radios. Fungi also destroyed a lot of equipment belonging to the British army in India (Flerov 1972).

The effect of fungi and bacteria on human activities is illustrated by Photo 5.105.

5.12.2 Terrestrial Plants

Different *categories* of plants contribute to biodeterioration: mosses, grasses, shrubs and trees. Devastating effects of plants may be due to things such as wedging by their *roots*, creating conditions for *penetration of moisture* and the destruction of *binding materials* with root secretions. Biodeterioration arises during the growth of plants, on both *horizontal* (such as foundations, roofs, roads and sidewalks) and *vertical* (such as walls and embankments) surfaces.

Plants have damaging impacts on the following *types* of human activity: (1) industrial and residential development, (2) motor vehicles and (3) railroad transportation.

Impacts on *industrial and residential construction* occur through the destruction of roofs (especially flat roofs) and walls. Mosses settle in areas of high humidity, often colonizing the lower parts of brick walls. Herbaceous and woody plants can overgrow a structure.

Different kinds of *birch species (Betula)* cause major damage in the temperate zone. Their small and light seeds are dispersed by wind; they root in crevices of brick walls and niches filled with sand and dust (Ilyichev 2003). The perennial shrub/bushes *caper* (*Capparis*) is the most hazardous plant species in central Asia. These plants have fast-growing roots. The main caper root reaches a length of 16–17 m and a thickness of 15 cm. They penetrate deep into masonry, at seams between bricks. These plants destroy binding materials with their secretions, mechanically break lining materials, and cause foundations and plaster to crack. In addition, they create conditions for moisture penetration into a structure.

The impacts on *automobile transport* are partly due to plants taking root in cracks in the asphalt coating on roads. The most common species here are dandelions and plantain. With the growth of the root system, cracks widen rapidly, destroying asphalt. A similar situation arises in places of contact between horizontal and vertical surfaces (e.g. at the edge of curbs). Another problem is fouling of drainage wells, mostly by dandelions at junctions with asphalt.

The impact on *railway systems* relates to plants growing near sleepers. Their roots penetrate under the sleepers, contributing to their loosening and potential washout (Ilyichev 2003).

The role of terrestrial plants in biodeterioration is illustrated by Photos 5.106 and 5.107.

5.12.3 Insects

The following *categories of properties* of materials affect the damage that can be caused by insects: (1) organoleptic, (2) antibiotic and (3) constructive (Zhuzhikov 1983).

Organoleptic properties of a material have an impact on visual, chemical and tactile receptors in insects. Attractiveness of a material to an insect depends on a defined set of characteristics and properties that it prefers when searching for food, oviposition sites, shelter, etc.

Material stability against insect damage depends on its organoleptic properties, which can be of two *types* (Zhuzhikov 1983). The *first* type of material stability is due to its lack of one or more attracting properties. The *second* type is due to the presence of repelling properties.

Antibiotic properties of a material depend on characteristics such as its toxicity or lack of nutrients. The most impregnable materials are those on which a population of certain insect species are unable to sustain their existence.

Structural properties are also important. Since materials are damaged only by insects with biting mouthparts, the high hardness of a coating or the material itself will contribute to its preservation (Zhuzhikov 1983).

Insects cause only *mechanical damage* to materials, mainly in the process of searching for food. If a product is suitable for insects to colonize and has cavities, then internal contamination is possible. Damage to materials also occurs when insects develop a colony in cavities of a material and use its particles for their construction activities.

The *most significant insects* are representatives of the orders of beetles, butterflies, biting lice, termites and bristletails. Based on the way they feed, they are described as keratofagous or xylophagous. *Keratophagous insects* are able to digest and assimilate keratins – proteins that form the basis of the horny layer of skin and hair of mammals and the feathers of birds. *Xylophagous insects* feed on plant materials.

The most *hazardous pests* on materials of animal origin are *skin/carpet beetles* (Dermestidae) and *fungus/clothes moths* (Tineidae). These insects inhabit all geographic zones, except tundra, but their maximum population and species diversity are observed in areas with dry and hot climates.

Most *skin/carpet beetles* cause damage to leather, fur, feathers, wool and wool products, meat and meat products, dried and smoked fish, book bindings, glue,

Photo 5.106 Devastating effects of plants may be due to things such as wedging by their roots, creating conditions for penetration of moisture and destruction of binding materials with root secretions. The photo shows a tree growing on the flat roof of a building in Vladivostok (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 19 June 2005)

Photo 5.107 Biodeterioration arises during the growth of plants on both horizontal (such as foundations, roofs roads and sidewalks) and vertical (such as walls and embankments) surfaces. The ash sprout is growing from a failure in a revetment wall in Vladivostok (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 19 June 2005)

copra, grain and grain products. In addition, they are destructive to cardboard, asbestos, cotton, cotton fabric and synthetic fabrics, linen, plastic, tobacco and telephone cables. These insects damage things such as zoological and entomological collections and herbariums (Ilyichev et al. 1987).

Fungus/clothes moths cause damage when they feed on furs, wools, felt pads in devices, heat and sound insulating felt material, leather bindings of old books, woollen fabrics and zoological collections. The total amount of wool destroyed by a single moth brood is 50 g/year. Harmful activity of

Photo 5.108 The Formosan subterranean termite (*Coptotermes formosanus*) is often nicknamed the 'super-termite' because of its destructive habits. This is because of the large size of its colonies, and the termites' ability to consume wood at a rapid rate. A mature Formosan colony can consume as much as 400 g of wood a day and severely damage a structure in as little as 3 months. Damage of a sawdust concrete partition by Formosan subterranean termites is shown here (Photo credit: Scott Bauer, USDA Agricultural Research Service, Bugwood.org)

clothes moths is possible only at temperatures above +15°C (Protection against corrosion, ageing and biodeterioration 1987, vol 2).

Cockroaches are also insect pests of keratin-containing materials. There are more than 4,000 species, and they live mainly in the tropics and subtropics. Cockroaches can damage food products, leather, book bindings and indoor and greenhouse plants (Biological encyclopaedic dictionary 1986).

Insects associated with *timber* can be divided into pests of *fresh wood* timber and pests of *dry wood* materials, buildings and furniture. Harvested logs are usually damaged by bark beetles (Scolytinae) and long-horned beetles (Cerambycidae) and red palm weevil (Curculionidae, *Rhynchophorus ferrugineus*); they are occasionally damaged by jewel/metallic wood-boring beetles (Buprestidae); ship timber beetles (Lymexyidae); and horntails (Siricidae). Beetles sometimes create deep wormholes (for example, certain types of long-horned beetles penetrate into wood for 6–12 cm), which *reduces* the yield of intact material from logs. In the northern part of Minnesota (United States), capricorn beetles kill approximately 5% of harvested timber, turning it into the category of 'firewood' (Karasev 1983).

Dry timber and *wood products* are vulnerable to some insects: certain capricorn beetles or long-horned beetles, death watch beetles (Anobiidae), true powder-post beetles (Lyctinae), auger beetles (Bostrichidae) and termites (Isoptera). Of the *beetles,* the most damage is caused by death watch beetles (Anobiidae), which damage building structures, furniture and various wood products, especially old icons and museum exhibits.

The greatest risk for buildings and wood are *termites*. This order has approximately 2,600 named species. The northern and southern borders of their habitat coincide roughly with an average annual isotherm of +10°C (Ilyichev et al. 1987). The global distribution of termites is shown in Fig. 5.35.

There are soil and dry-wood termites. *Soil termites* can obtain forage outside their nest, and they can cover considerable distances. Often, they gnaw through various non-food materials in their path and bring soil to various cavities, contaminating equipment.

Dry-wood termites gnaw tunnels and chambers only in wood, and they do not go beyond their habitat limits. They can also colonize other materials containing cellulose (such as plywood, cardboard, fibreboard and chipboard). They can cause deterioration of non-food materials if they come into contact with infested wood.

Damage from insect activity is significant. Annual losses across the globe from moth damage to wool fabrics are estimated at US$500 million. Significant damage is caused by termite activities, and it continues to grow. A detailed assessment of losses in the United States is available. Termite-related losses amounted to US$40 million annually according to a 1938 report, US$100 million in 1950, US$250 million in 1960, US$500 million in 1970, and US$1.17 billion in 1982 (Ilyichev et al. 1987). Nan-Yao Su (2002) estimated

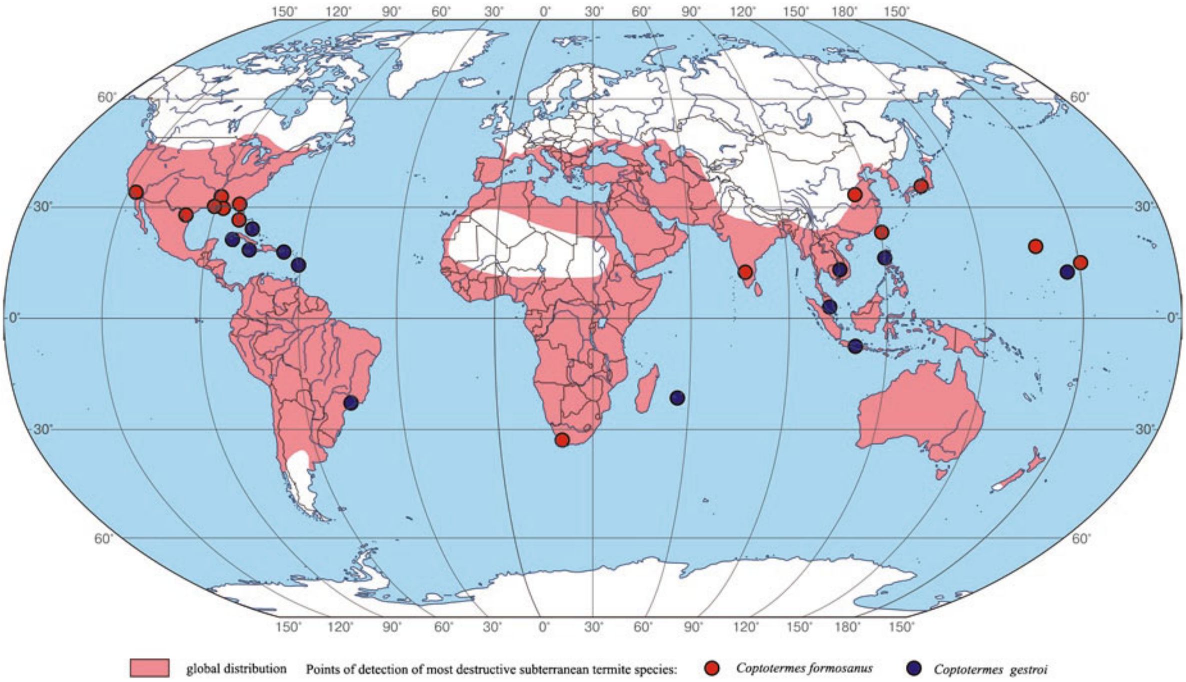

Fig. 5.35 Global distribution of termites (Adapted from Edward and Mill (1986), Su (2003))

Photo 5.109 Clothes moths cause damage when they feed on furs, wools, felt pads in devices, heat-and sound-insulating felt material, leather bindings of old books, woolen fabrics and zoological collections. The total amount of wool destroyed by a single moth brood is 50 g/year. A sheepskin that was practically eaten by moths is shown (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 21 February 2004)

the *annual economic losses* due to termites at US$11 billion for the United States and US$22 billion for the globe.

There have been cases of damage caused to *electric* power *cables* in a steel mill, to the automatic lock system for a high-speed *railway*, and to *radars* at an airport. These incidents sometimes led to accidents with fatalities (Ilyichev et al. 1987).

The impacts of these insect species on human activities are illustrated by Photos 5.108 and 5.109.

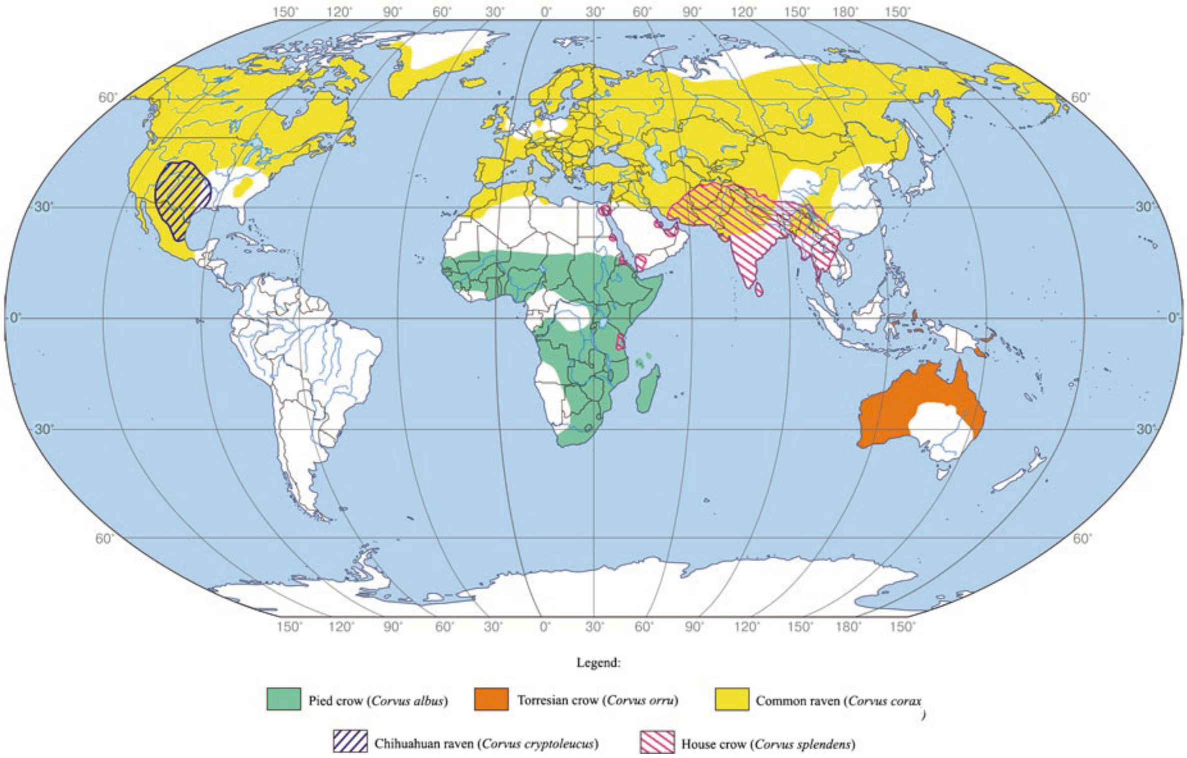

Fig. 5.36 Global distribution of some species of crows (http://commons.wikimedia.org/wiki/wiki/File:Corvus_splendens_map.jpg; http://en.wikipedia.org/wiki/File:Corvus_cryptoleucos_map.jpg; http://en.wikipedia.org/wiki/File:Corvus_corax_map.jpg; http://en.wikipedia.org/wiki/File:Corvus_orru_map.jpg; http://en.wikipedia.org/wiki/File:Corvus_albus_updated_map.jpg)

5.12.4 Birds

The total *number* of bird species is around 10,000; approximately 100 of these are associated with biodeterioration. The *characteristics* of most of them are (Ilyichev et al. 1987) (1) abundance, (2) synanthropy (having a lifestyle related to human activity), (3) prevalence and (4) increasing population.

Activities of birds that cause biodeterioration are determined by penetration of *avifauna* into the environment of human activity and *human expansion* into the living space of birds. Birds cause biodeterioration in the following *human environments* during the course of their activities (Sokolov 2008): (1) human living space, where they collide with vehicles; (2) natural habitats, which are broken and changed by man; (3) agricultural production, which is consumed or polluted by birds; (4) urban landscapes are filled with birds during nesting and migration; and (5) various technical devices and structures are used as shelters or for nesting.

The *most important* species causing biodeterioration are gulls, pigeons, starlings, rooks, ravens, storks, herons, swallows, woodpeckers, geese, ducks and some daytime predators (falcons, hawks and eagles). The global distributions of some species of crows are shown in Fig. 5.36.

They cause damage to a very wide range of materials, technical equipment, facilities, raw materials and materials in the production, storage, transportation and processing stages. The *following structures* are damaged most significantly by their activities: (1) transportation; (2) power and communication lines; (3) cultural monuments, architecture and industrial institutions and (4) different large-scale equipment.

Collisions of birds with aircraft are discussed in Sect. 5.12.4.1.

Photo 5.110 Birds, to a certain degree, complicate the maintenance of residential structures. For example, they withdraw an oakum from blockhouse slots for nest construction and contaminate walls, windows and other structures with their droppings The damage done by Eurasian green woodpeckers (*Picus viridis*) to cellular polystyrene insulation of an exterior wall is shown. The house was constructed in a clearing in the woods (Photo credit: V.B. Primak, Pacific Institute of Geography, Vladivostok, Russia, 18 December 2005)

Photo 5.111 A business in central Melbourne (Australia) suffered as sulphur-crested cockatoos repeatedly stripped the silicone sealant from the plate glass windows. The photo shows sulphur-crested cockatoos damaging the Sturt Mall shopping centre facade made of polystyrene (Photo credit: http://en.wikipedia.org/wiki/Cockatoo)

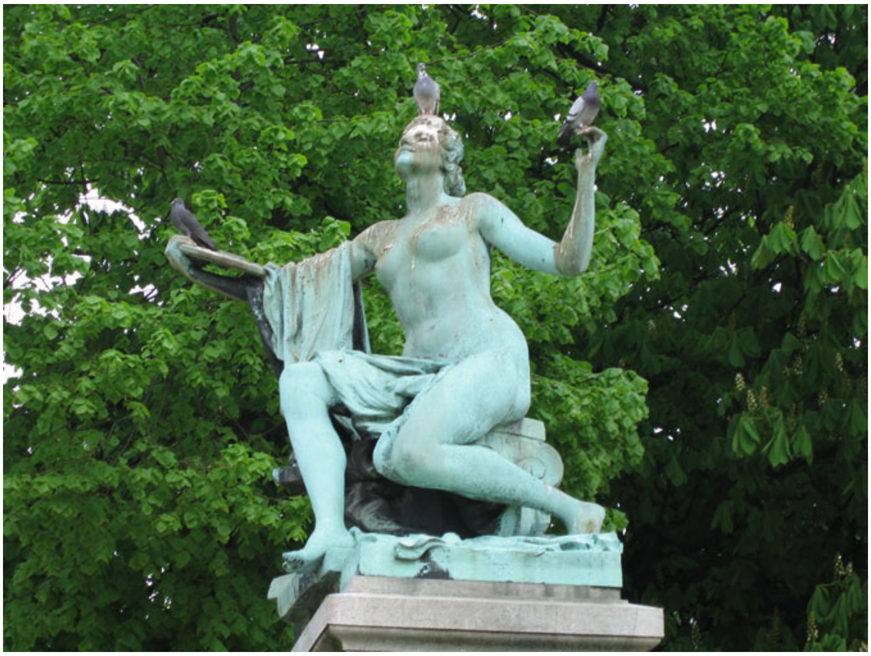

Photo 5.112 The activities of birds often lead to catastrophic biodeterioration of cultural monuments. Sculptures are often covered with a solid white shell of pigeon droppings. In addition to the unpleasant appearance of pigeon droppings, they cause biological corrosion of metal monuments and destruction of the materials of sculptures. The photo shows an affected monument in Brussels, Belgium (Photo credit: Vincent Vanderveken, 2008)

Damage to *power and communication lines* is due to the following *factors*: (1) nesting birds on power-line towers, (2) use of poles and wires as a place of rest and (3) woodpecker damage on tips of wooden electric power grid poles.

The influence of birds nesting on *power lines* is due to the following: *first,* bird nests can be very heavy. For example, a stork's nest can weigh up to 500 kg (Sokolov 2008). *Second*, scraps of wire often are used in their structures, resulting in short circuits and power outages affecting railways, factories, livestock farms and other facilities. For example, common rooks' nests (in one case, there were about 55 nests on a single tower) can cause blackouts (up to 2.5 incidents per single pole during the breeding season).

When heavyset birds use power lines and poles for short landings or as *resting spots,* accidental short circuits can occur. These are caused by a bird's large-sized wings or jets of fluid faeces, which are good electric conductors.

Thus, power line outages caused by birds are related to the *following*: (1) short circuits caused by the stretched wings of large birds (storks – Ciconiidae, diurnal birds of prey or Falconiformes), (2) short circuits at power transformers caused when they clean their bills on wire, or peck their food (ravens – Cordivae, or often by the hoodie, *Corvus cornix*), (3) throwing various items on wires, which is inevitable during the nesting period and (4) contaminating insulators on poles with faeces.

Woodpeckers are responsible for a *third type of damage* (mostly great spotted woodpeckers, *Dendrocopos major).* These birds scoop out the tops of wooden poles, most frequently around insulators. Fungal flora develop in the deep cracks that are formed. Decay of the top of a pole sometimes results in loss of insulators.

The activities of birds often lead to catastrophic biodeterioration of cultural *monuments* and *architecture*. *Sculptures* and *buildings* are often covered with a solid white shell of pigeon droppings. In addition to the unpleasant appearance of pigeon droppings, they cause biological corrosion of metal monuments and destruction of the materials of buildings and sculptures. Great damage is caused by ravens and jackdaws.

They tear off sections while gilding with their talons when they try to land on the domes of *churches*, provoking accelerated corrosion.

Seagulls are a very important biodeteriorating species in Western cities. They nest on flat building roofs, contributing to biocorrosion of the *roofs*. *House martins* (*Delichon*) deface facades and complicate the upkeep of buildings. They glue pieces of clay and dirt when they build their nests in places such as on bridge trusses and under the balconies and cornices of buildings.

Bird *nesting activities* are main causes of biological damage to large *equipment* (used in road construction, forest reclamation, transportation and other activities) and other *structures* of great size (repair facilities, assembly shops, markets, stations, airports, mass-entertainment facilities, etc.). For example, there are cases when nesting material fell into complex machinery for production of polyethylene, disabling it. A metal electrode fell from a jackdaw's (*Corvus monedula*) nest, punching a sheeting wing in a hangar at an airport in Sheremetyevo (Russia) (Protection against corrosion, ageing and biodeterioration 1987, vol 2).

There is a widespread phenomenon of birds nesting in *transportation vehicles* and out-of-commission equipment. For example, in a treeless area where places for starlings to nest are very scarce, they built their nests in the cavity of an AN-2 aircraft, in the upper wing, bringing their building materials through holes in the aileron pushrods (Yakobi 1972). It is not uncommon to find bird nests in *tractor engines*.

Activities of birds that cause biodeterioration are illustrated by Photos 5.110–5.112.

5.12.4.1 Bird Strikes

The *first case* of a birdstrike, which had tragic consequences, was recorded in 1912 in California (United States). A seagull collided with a plane and broke the steerage, which led to the death of the pilot (Ilyichev et al. 2006).

Incidents began to occur more frequently with the development of aviation. Increases in flight *speeds* have increased the *risk of collisions*. Besides, increased aircraft speeds make it harder for birds to avoid collisions. *Differences* in the speeds of military and civilian aircraft are the reasons why damage from bird strikes is greater in military aviation. For example, in the Swiss air force, there are 9.7 collisions for every 10,000 h of flight, while in passenger airlines, the rates are 3.2–7.6 per 10,000 h of flight (Ilyichev et al. 1987).

The force of impact of a birdstrike depends on the following *factors*: (1) impact speed, (2) bird weight, (3) bird density, (4) bird rigidity, (5) angle of impact, (6) impact-surface shape and (7) impact-surface rigidity. *Starlings* have the maximum body density – 27% higher than that of a European herring gull (*Larus argentatus*). That is why they are called '*feathered bullets*' or 'starling feathered bullets'. The global distribution of the European starling is shown in Fig. 5.37. With an aircraft speed of 555 km/h, a collision with a European starling (*Sturnus vulgaris*; weight 85 g) yields a force of 4,060 kg and with a Canada goose (*Branta canadensis*; weight 6.8 kg), it is 37,200 kg (Sharing the skies 2001).

Collisions with birds happen at different *altitudes*. The *highest* recorded altitude is 12,150 m, when a plane collided with a Rüppell's vulture (*Gyps rueppellii*) near the Ivory Coast (Côte d'Ivoire). However, *most bird strikes* (68.2%) occur during take-off and landing; that is, at low altitudes (Ostapenko et al. 1984).

The number of collisions at *take-off* is much higher; V.E. Yacobi (1972) explains: birds that are sitting on a runway, or close to it, notice a landing aircraft on the skyline at a greater distance than one taking off against a background of earth and green trees. 23.7% of collisions occur during aircraft turns. As it sees a plane, a bird can extrapolate the point of intersection with the trajectory of the plane and turn aside. However, when an aircraft turns, the bird becomes disoriented.

At present, some *statistical regularities* of collisions are known. In collisions with civilian aircraft, birds fall into an engine in 39.4% of cases; into the fuselage, 32.4%; into glass cockpits, 16%; and in front of the fuselage, 7% (Ilyichev et al. 1987). In a high percentage of hits on the engine, the bird is sucked in.

The *species composition* of birds involved in bird strikes is determined largely by the geographical position of the airport. *Gregarious* birds are less dangerous, in general, because if one of them sees the danger, it gives signals to the whole flock and flies away from the path of the aircraft. Therefore, despite the predominance of gregarious birds, they accounted for only 23.8% of all cases of collisions.

In the United States alone, 3,200 aircraft collide with birds each year (Conover et al. 1995). It is believed that there are eight collisions for every thousand flights of

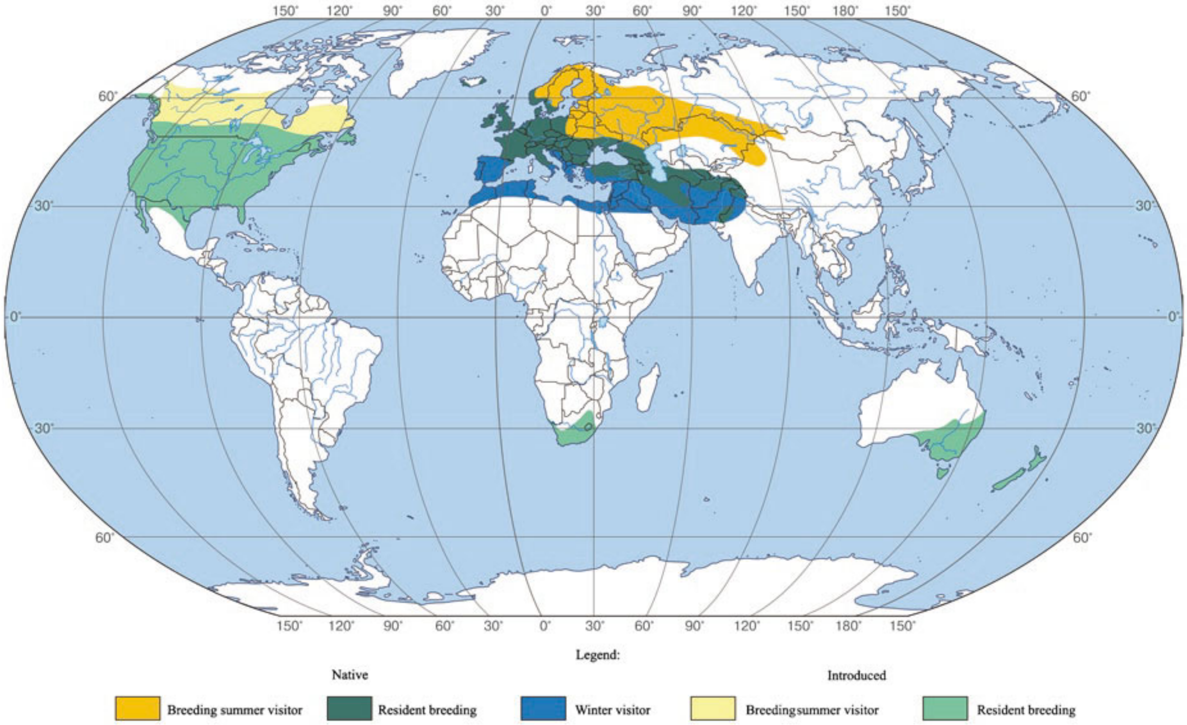

Fig. 5.37 Global distribution of European starlings (*Sturnus vulgaris*) (http://en.wikipedia.org/wiki/File:Sturnus_vulgaris_map.png)

Photo 5.113 As to the biological damage done by birds, their collisions with aircraft are the most significant. Most such collisions occur on take-offs and landings of airplanes, and in these cases, birds fall into engines, wings, cockpit windows and the forward fuselage. The photo shows a helicopter after a collision with a Eurasian wigeon (Photo credit: Phil Mountain, UK Food and Environment Research Agency)

Photo 5.114 Differences in the speeds of military and civilian aircraft are why damage from bird strikes is greater in military aviation. The photo shows the consequences of a collision of a Harrier with a bird (Photo credit: Phil Mountain, UK Food and Environment Research Agency)

Photo 5.115 With an aircraft speed of 555 km/h, a collision with a Canada goose (*Branta canadensis*; weight 6.8 kg) yields a force of 37,200 kg. The #1 engine on this KLM B-747 suffered an uncontained failure as a result of a collision with Canada geese while landing at Calgary International Airport. Leading edge devices were also damaged (Photo credit: Transport Canada)

civil aircraft (Ilyichev et al. 1995). The *most serious accident* occurred on 4 October 1960; a Lockheed L-188A Electra aircraft collided with a flock of European starlings immediately after take-off at an airport in Boston (United States). Multiple birds were sucked into three of the four turboprop engines. The plane crashed into Boston Harbor, killing 62 people out of 72 on board (http://aviation-safety.net/database/1960/601004–0.htm).

The *total death toll* since 1988 is approximately 200 people (http://en.wikipedia.org/wiki/Bird_strike). The damage caused by collisions of aircraft with birds is very high, primarily due to the high cost of aviation equipment. The annual damage from such collisions with birds in North America is estimated at US$500 million (Sharing the skies 2001), and the *losses on a global scale* are US$1.2 billion (Allan and Orosz 2001).

Consequences of bird strikes are illustrated by Photos 5.113–5.115.

5.12.5 Mammals

The most significant species of mammals that cause biodeterioration are *rodents* (Rodentia). A characteristic feature of members of this group is their *powerful jaw* arrangement. Well-developed muscles can create considerable effort in chewing and gnawing. For example, the Brown/common rat (*Rattus norvegicus*) generates a force of 940 kg/cm^2, and the squirrel (Sciuridae) generates a force of 1,500 kg/cm^2 (Ilyichev et al. 1987). *Rodents' teeth* grow throughout their life, so regular chewing/gnawing is necessary to keep them from growing too long. Brown rats gain 2 mm on their upper incisors and 3.45 mm on the lower incisors weekly (Ilyichev et al. 1987).

Gnawing activity is not only for *feeding*. There is also *non-food* gnawing, which has different *functions*: (1) construction of housing (building nests, digging holes), (2) orientation behaviour (to study unfamiliar objects, these animals use biting), (3) the need to grind down incisors and (4) getting rid of obstructional barriers.

Animals may use different structures for *shelter* or *nesting sites* and as substrate for reproductive purposes (pupation); they use all sorts of materials for nests. In the process of this activity, materials can be destroyed, buried in soil, contaminated with waste products (products of metabolism), or otherwise damaged, and the damage can be significant (Sokolov 2008).

Distinguished representatives of *rodents*, in terms of their destructiveness, are representatives of the following *families*: Muridae (different kinds of mice, rats, gerbils and others); Cricetidae (hamsters, voles, lemmings and New World rats and mice) and the Sciuridae family (ground squirrels). Lagomorphs (Lagomorpha) include pikas, hares and rabbits. The most important representatives of ungulates are wild boar, deer, elk and cattle. The global distributions of some species of rats are shown in Fig. 5.38.

Mammals affect the following structures and *types of human activity*: (1) communications lines, (2) storehouses, (3) residential and industrial premises, (4) hydraulic engineering installations, (5) embankments, (6) airfields, (7) industrial facilities and large equipment, (8) pipelines and (9) livestock.

Impacts on *communications* occur in all environments. *Communication lines* exposed to the air are damaged by *squirrels*. Such cases have been recorded repeatedly in the United States (Emelyanova and Deryagina 1983). *Underwater* cables are damaged by *beavers*.

Underground cables can be damaged by many mammals. Boars damage cables as they dig through the top layer of soil in search of food; deer and elk cause damage as they move or graze. Different types of gophers, jerboa and mole rats damage cables when digging holes. Mice and rats gnaw cables for a variety of reasons (the need to grind down incisors, removing obstacles that impede their passage, biting to investigate unfamiliar objects).

Damage to *cables* and *wires* often leads to accidents and fires, with loss of lives, as well as to interruptions of communications and movement of trains. Approximately 20% of *fires* in the United States happen due to short circuits in cables damaged by rats. Rats repeatedly interrupt the movement of electric trains in Japan due to damage to cables and light signal alarm groups (Emelyanova and Deryagina 1983).

Rodents are a main cause of damage to different *materials* and *food* in warehouses. The list of materials damaged by them is *extremely long*. These include *things such as* fabrics of different fibres, non-woven materials, natural and artificial leather, synthetic films and pipes, asbestos materials, rubber, plastics, paper, cardboard, wood, chipboard and finishing materials (wallpaper, linoleum and plastics).

The *possibility of damage* by rodents depends on a material's hardness, structure (dense, porous, viscous) and the nature of its surface. Accessibility and availability of the edge of an object promotes damage. Surface seams, protrusions and holes provide places for rodent incisors to latch on to.

Destruction of *food* occurs during *biting*. Each black rat (*Rattus rattus*) consumes US$15 worth of food every year. There are approximately 1.25 billion black rats in the United States, and the country

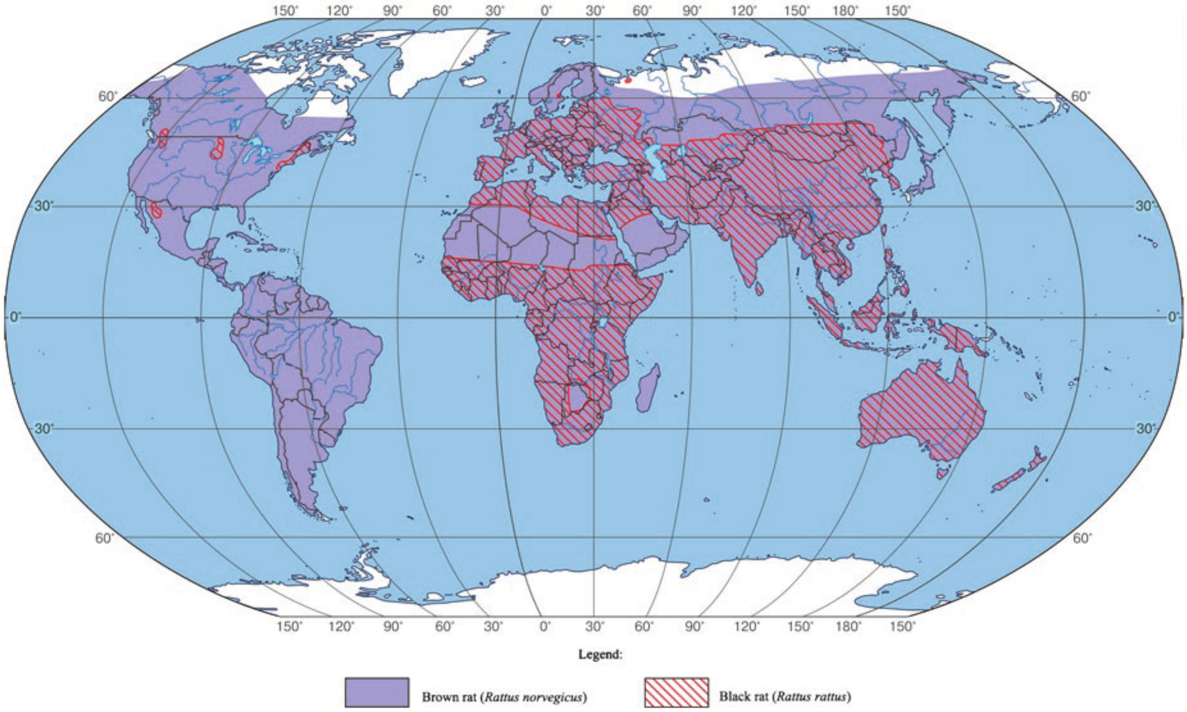

Fig. 5.38 Global distribution of some species of rats. (http://en.wikipedia.org/wiki/File:Brown_rat_distribution.png; http://commons/wikimedia.org/wiki/File:Black_rat_range_map.png)

loses approximately US$19 billion worth of food annually (Mitchell 2001). In the endeavour to get food, rodents damage containers and packaging and gnaw holes in the floors and walls of barns, warehouses and granaries.

Damage to *materials* also occurs during rodent *nesting activities*. In building their nests, rodents use materials such as paper, cloth, insulation materials, foam and rubber. They cause damage while examining unfamiliar objects or just grinding down their ever-growing incisor teeth.

In addition to direct destruction of materials, rodents inflict *collateral damage*. For example, damage to sealed films on instruments leads to damage of the instruments themselves. Damage to food packaging also causes contamination and spoilage. Besides, rodents contaminate materials with their faeces, urine and hairs.

On residential and industrial premises, rodents cause damage with their *building activities*. For example, rats do widespread damage to wall panels with metal cladding and heat insulation foams. Rats gnaw at foam, damaging as much as 30–40% of the insulating layer, which reduces its heat insulating properties. Short-tailed bandicoot rats (Muridae) and mole voles (Cricetidae) cause damage by their *burrowing activities*. They create complex burrows and, thus, damage earthen floors and mud walls of adobe buildings.

Effects on *water systems* are also largely due to rodents' *burrowing activities*. Rodents inhabit banks of canals behind facing slabs in dams. They burrow holes and burrows below water level. This causes increased filtration and often leads to destruction of dams, sometimes causing floods. Muskrats (*Ondatra zibethicus*) cause most of the damage to irrigation systems in Western Europe. In the former USSR, there was also the giant mole rat (*Spalax giganteus*), the great gerbil (*Rhombomys opimus*), the northern mole vole (*Ellobius talpinus*) and the short-tailed bandicoot rat (*Nesokia indica*) (Sokolov 2008).

The *burrowing activity* of rodents leads to the erosion of road and railway *embankments*. The common hamster (*Cricetus cricetus*) and great gerbil (*Rhombomys*

Photo 5.116 Rodents are a main cause of damage to food in warehouses. Destruction of food occurs during biting. Each black rat (*Rattus rattus*) consumes US$15 worth of food every year. Trying to get food, rodents damage containers and packaging and gnaw holes in the floors and walls of barns, warehouses and granaries. The photo shows rats in a storeroom in Germany (Photo credit: H. Zell, 16 August 2009)

Photo 5.117 One rodent control technique is prevention of their access to structures. The photo shows a storehouse built on piles with upper parts that end with stone plates, precluding the intrusion of rodents into the structure. The photo was taken in Zermatt (Switzerland) (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 3 September 2006)

Photo 5.118 Mammals create danger for different transportation vehicles. When large animals are allowed access to aircraft movement areas, a high-risk situation always results. The photo shows caribou on a runway in Canada (Photo credit: Transport Canada)

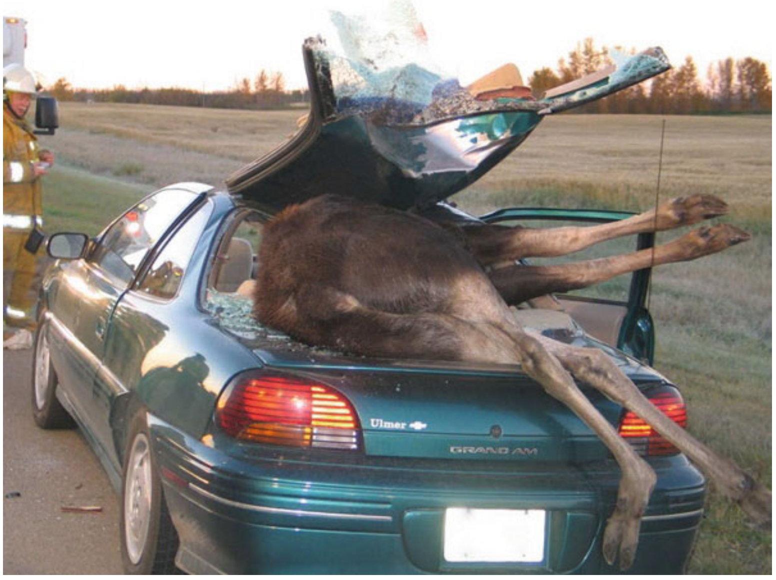

Photo 5.119 The problem of collisions of automobiles with mammals is very acute, and in this case, danger to the lives of people and animals is created. The photo shows the scene of a car accident involving a moose near Maidstone, Saskatchewan, Canada. A woman was driving home and hit the moose with her car. The moose ripped the roof right off and ended up lying on the back trunk, with its head on the back seat. The woman had a few broken ribs (Photo credit: http://www.zenwaiter.com/moosephoto.htm, November 2006)

opimus) create holes and move embankments. These activities promote differential settlement of embankments, breaking the continuity of road pavements, which makes roads difficult to navigate. There is a similar impact of the animals on *airfields* of small aircraft. The various burrowing animals (moles, mole rats, shrews, etc.) destroy the runway surface, which may cause accidents (Emelyanova and Danilkina 1983).

Rodents typically cause damage to *transport vehicles* during their long stops. Rodents penetrate deeply into devices and damage electrical cables, rubber gaskets, hoses and tubes, foam, upholstered seats and booths, blankets and other materials. There are reports of damage to wiring of US helicopters during the Vietnam War, to rubber insulation and pads of aircraft on the Stalingrad front in autumn 1942, and to wires by rats in two TU-134 aircraft during their stay in one of Africa's airports in 1973 (Emelyanova and Danilkina 1983). They cause similar damage to various types of machinery, generators and other devices.

In *power stations,* rodents damage power cables, and short circuits also occur due to contact of animals with boxes of transformers and distribution boards (Sokolov et al. 2008). In the recent past, when computers were *extremely bulky*, they were damaged very frequently. When house mice damaged computer cables in the central bank of Buenos Aires (Argentina), it halted operations at the stock exchange and other banks of the city (Emelyanova and Deryagina 1983).

Cases of damage to *pipelines* by mammals usually occur when pipe structures overlap along reindeer migration routes. Such episodes have been recorded in Alaska (Protection against corrosion, ageing and biodeterioration 1987, vol 2). It also has been noted that pipelines have been damaged by great gerbils (*Rhombomys opimus*) (Sokolov 2008).

Rodents cause some problems to *livestock rearing*. Inhabiting barns, rats gnaw numerous holes in the floor. Cattle can break their legs when they fall into the holes.

The effects of biodeterioration caused by mammals on human activities are illustrated by Photos 5.116–5.119.

5.12.6 Fish

Biodeterioration caused by *fish* is usually accidental. They affect the following *types of human activity*: (1) shipping, (2) fishing and (3) submarine communication cables.

Some *large fish* – those with long, narrow bodies represent a danger to small *boats*. These fish include swordfish (*Xiphias gladius*); marlin (Istiophoridae) and garfish (*Belone belone*). Several cases of *such collisions* with ships are described in a book by E.R. Ricciuti (1979). Presumably, all these collisions were accidental. It has been surmised that the big fish were simply in pursuit of small fish that were hiding under boats, and marlin and swordfish just did not have enough time to change their course to avoid collisions. There also have been sporadic collisions with surfboards and boats by *sawfish* (Pristidae) (Orlov 1998).

Fish attacks on *mini-submarines* have been recorded repeatedly, especially in deep waters. For example, the American research submarine *Alvin* was attacked by a *swordfish* (*Xiphias gladius*) on the Blake Plateau off the east coast of Florida (United States) on 6 July 1967 during a geological survey. The sword struck the polystyrene shell of the outer hull; fortunately, for the crew of three men, it did not damage the power cable underneath. The crew was forced to come up expeditiously from a depth of 610 m (http://www.onrglobal.navy.mil/focus/ocean/vessels/submersibles2.htm).

Different species of sharks have negative impacts on the *fishing industry*. In many areas, they are a real scourge, being responsible for thousands of miles of broken nets and longlines, and huge shoals of fish have been destroyed (McCormick et al. 1992).

Damage caused by fish to *submarine cables* is not a typical example of their impact on human activities. Nevertheless, such a case has been recorded. An intercontinental telegraph cable was laid along the bottom of the Indian Ocean at a depth of 1,400 m. When the cable was raised to the surface for repair, it was discovered that the cause of failure was a long, thin *goblin shark's* (*Mitsukurina owstoni*) tooth, which had pierced the metal sheath (Ricciuti 1979).

5.12.7 Fouling

The term *fouling* refers to a community of plants and animals living on a solid substrate. The *total numbers* of fouling species are over 3,000 species for anthropogenic substrates and 20,000 species for natural substrates (Ilyichev et al. 1987). The *total area* of submerged artificial marine substrates is approximately 200,000 km^2 (Zvyagintsev 2005).

There are *two kinds* of aquatic fouling: freshwater and marine fouling. The most important *freshwater* fouling organisms are the bryozoan (Ectoprocta), zebra mussel (*Dreissena polymorpha*) and mosquito larvae (Chironomidae) (Protection against fouling 1989). The biomass of fouling provided by zebra mussels can reach 20 kg/m^2 (Protection against corrosion, ageing and biodeterioration 1987, vol 2).

Marine fouling occurs mostly in coastal waters. It consists of a large number of species and biomass estimated in kilograms and tens of kilograms per square metre. Areas of similar ship fouling are shown in Fig. 5.39. The *maximum amount of fouling* recorded was present on the stilts of oil platforms off the coast of southern Vietnam. It was over 300 kg/m^2(Zevina and Negashev 1995).

The most *important* fouling, in terms of its impacts on human activities, is marine fouling of the following

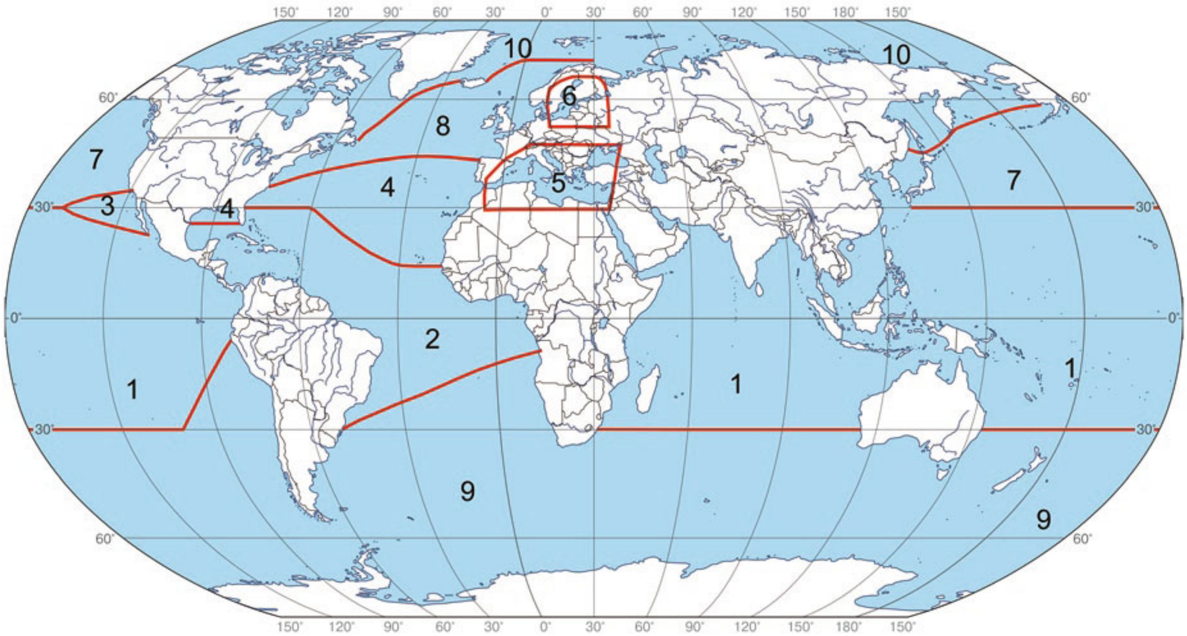

Fig. 5.39 Areas of similar ship fouling (Marine fouling and its prevention 1952). Numbering of the areas in arbitrary. and is not intended to indicate relative fouling (Reproduced with permission of U.S. Naval Institute, Annapolis, Maryland)

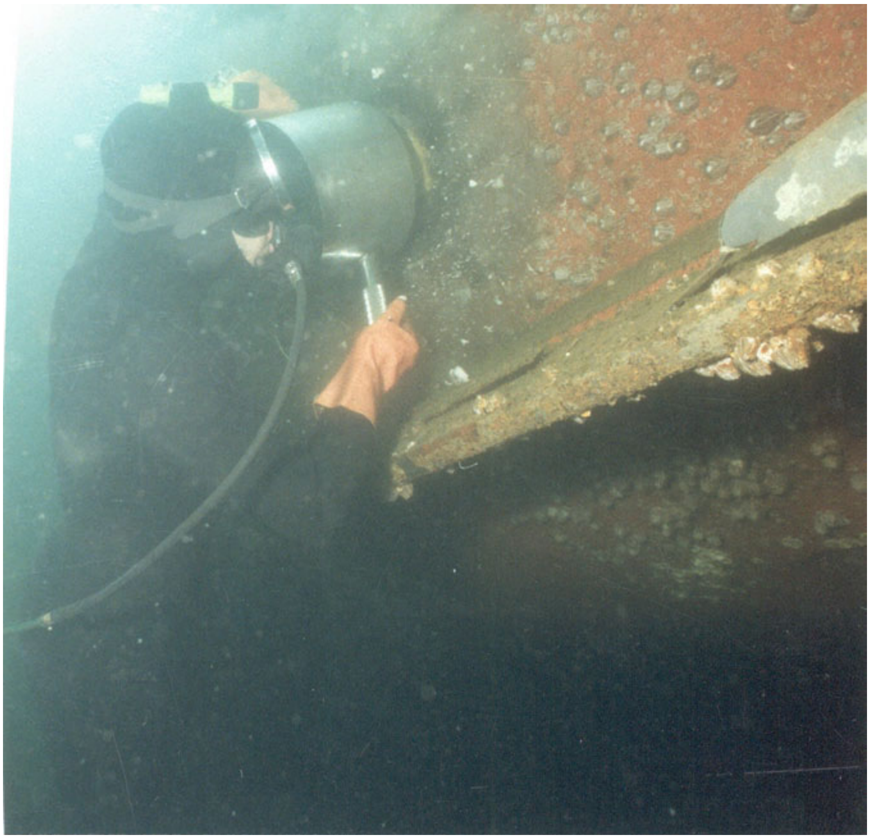

Photo 5.120 Fouling increases the roughness of a hull surface, directly affecting the energy consumption of a moving vessel. One of the most common ways of fouling control is mechanical removal of fouling organisms by the use of a hydraulic single brush, scraper, or other device. The photo shows removal of sea acorns through the use of a hydraulic single brush (Photo credit: George Savvidis, summer 2002)

Photo 5.121 Hull fouling is not the only reason for reductions in propulsive quality. Propeller fouling also leads to increases in fuel consumption. The photo shows a fouled propeller in Australia (Photo credit: Defence Science and Technology Organisation, Australia)

objects: (1) actively moving objects (boat hulls and hydroplanes), (2) stationary hydraulic structures (pier piles, trestles, coastal wave power stations, oil and gas platforms), (3) the inner walls of water pipes and conduits, as well as onshore industrial installations and ships, (4) passively moving objects (navigational buoys, floating mines, deep-water wave power, fishing nets and seines, etc.) and (5) oceanographic instruments and sonar devices.

It is known that the *roughness* of a hull surface directly affects the energy consumption of a moving vessel. A 10-micron increase in underwater hull surface roughness creates 0.3% friction resistance on a moving boat and raises fuel consumption by 1% to maintain the original speed. Sometimes, fouling on the underwater parts of vessels increases roughness 2–3 times and leads to at least a 10% increase in fuel consumption (Tsukerman and Rukhadze 1996).

The combined *extent of surfaces* exposed to fouling on vessels was estimated at 2,000 km^2 in early 1970 (Protection against fouling 1989). Fouling greatly affects a ship's propulsive performance. It may slow a ship down by 50% (Ilyichev et al. 1987).

The intensity and composition of fouling depend on the following *factors* (Zevina 1994): (1) performance characteristics of a vessel (the slower the boat, the greater the fouling), (2) shape of ship hull (reduced water flow over protective ledges promotes fouling), (3) entrance into freshwater or heavily contaminated ports (leads to complete or partial

Photo 5.122 General patterns of settlement of fouling organisms on vessels are as follows. A rim of algae stretches along the waterline and below it. Animal fouling is situated below the algal belt and increases from the bow to the stern. Propelling screws have less fouling and are usually covered with barnacles (*Balanus*) and polychaetes (Polychaeta). The photo shows fouling of a submarine (Photo credit: Defence Science and Technology Organisation, Australia)

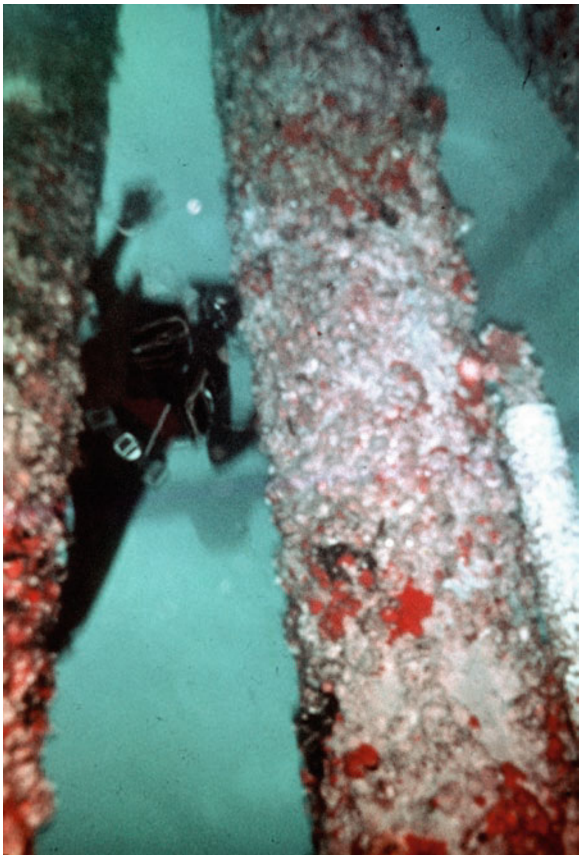

Photo 5.123 Among the serious problems is also fouling of piles of different structures. It can increase their diameters by 10–20 cm, which contributes to slacking and premature wear of structures due to sharp increases in the dynamic effects of waves on the structure. The fouled piles of a Vietnamese oil extraction platform in the South China Sea, 60 miles from the port of Vung Tau, are shown. The fouling biomass (*Cirripedia crawfish* predominates in the composition) is as much as 50 kg/m^2.. The picture was taken at a depth of 30 m (Photo credit: M.V. Propp, Institute of Marine Biology, Vladivostok, Russia, 1986)

elimination of fouling) and (4) length of stay in open ocean or near shore (determines fouling composition).

General *patterns of settlement* of fouling organisms on ships are as follows (Zevina 1972): A rim of algae stretches along the waterline and below it. Animal fouling is situated below the algal belt and increases from the bow to the stern. Propelling screws have less fouling and are usually covered with barnacles (*Balanus*) and polychaetes (Polychaeta). Rudders have very intense fouling, and composition is identical to that in the stern part of the hull.

Hull fouling is *not the only reason* for reductions in propulsive quality. *Propeller* fouling has some importance. Sometimes, it can be a major factor. For example, at sea trials of the fleet destroyer *McCormick*, it became clear that propeller fouling leads to a two-thirds increase in fuel consumption. Hull fouling can make take-off impossible for a hydroplane (Marine fouling and its control 1957).

The fouling of *aquatic piles* of various structures is a serious problem. Increasing the diameter of a pile facilitates loosening and wear on structures, as increases in resistance develop due to increased surface to wave friction. Pile fouling of oil platforms was represented by 22 species in the South China Sea after 2 years of operation (Photo 5.123). The average biomass was 20 kg/m^2; the maximum was 40/kg/m^2 (Zvyagintsev 2005).

Fouling of the inner walls of *ship water pipelines* can greatly reduce their capacity. The systems often become clogged by torn organisms near valves, nozzles and other bottlenecks.

Industrial seawater supply line fouling is also notable. The rate of fouling can be rapid. For example, mussels growing in power station water supply pipes amounted to 64 kg/m^2 in 21 weeks in Lynn, Massachusetts (United States) (Preobrazhensky 1986). There were 266 ton of shells removed from a tunnel of one power station on New Britain island (Papua New Guinea) in 1 year (Marine fouling and its control 1957).

Control of marine fouling is fundamentally important in setting *mines*. *First*, the fouling can disrupt the action of fuses. *Second*, fouling on a mine cable can make a mine plunge below the specified depth. Similar problems arise in maintaining networks established to protect against enemy submarines. The effect of fouling on fishing seines and nets is the same, plus fishermen injure their hands pulling barnacle-encrusted net gear (Zevina 1994).

Nautical buoys are subject to fouling to a very large extent. They usually have sufficient reserve of buoyancy, but the problem is that buoys and holding chains should be cleaned regularly for painting. Fouling internal pipes sometimes interferes with normal work on buoys with sirens.

Calcareous and siliceous shells of fouling organisms distort sound transmission. This complicates operations of *sonar devices* and *oceanographic instruments* that are based on transmission of sound waves in water.

Fouling hinders movements of working parts (screws, turntables, etc.) in oceanographic instruments that are based on principles of measurement. It hinders the operation of lighting, electrical, thermal and other sensors. Fouling usually distorts the readings on these instruments, sometimes totally impeding their operation.

With regard to *freshwater fouling*, the effects on human activities are much less. The most important effects are complications of waterworks and water supplies, and the mechanism of action is identical to that of marine fouling. Serious problems arise in the operation of Dnieper Hydroelectric Station (or DniproHES), and the Kakhovskaya and Tsymlianskaya Hydro Power Stations. They are associated with fouling of waterworks by *Dreissena polymorpha*. Similar problems were resolved during construction of technical water supply facilities for the Engels chemical fibre plant complex (Protection against fouling 1989).

Thus, fouling has the following *negative impacts* on human activities: (1) an increase in structural movement resistance in water, or flowing of water, due to increased roughness or volume of the structure; (2) changes in the weight and buoyancy of structures; (3) undesirable clogging of holes; (4) mechanical disruption of the operation of moving parts; (5) devastating effects on paint; (6) creation of favourable conditions for corrosion; (7) effects on sound transmission; and (8) deterioration of product quality.

Economic losses caused by fouling of vessels are estimated at US$10 billion (Zevina 1994) per year. They consist of *direct* costs (increased fuel consumption, increased wear of engine systems, cost of ships docking to clean their hulls, etc.) and *indirect* costs associated with loss of earnings while a fleet is out of service. Globally, total damage from marine fouling is currently US$50 billion per year (Adrianov 2007).

The effects of fouling on human activities are illustrated by Photos 5.120–5.123.

5.12.8 Marine Wood Borers

Marine wood borers are the animals that bore tunnels in wood structures located in salt water. There are approximately 200 species, which are represented mainly by bivalves and crustaceans. Wood borers are distributed in all parts of the world ocean except for very high latitudes.

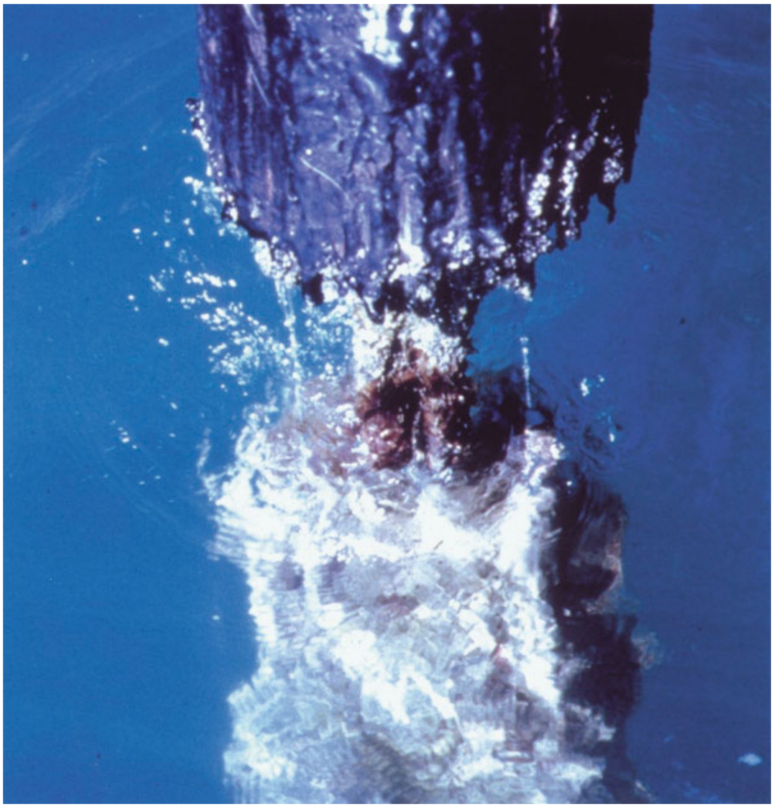

Photo 5.124 Although wood is rarely used in the construction of ship hulls anymore, it is still applied quite widely for hydraulic structures. Wet, soaked wood does not decay in seawater and may stay preserved for a very long time; however, it is exposed to the action of wood borers. The photo shows damage done by *Limnoria* to a pile of a US naval base pier in Puerto Rico (Photo credit: J.D. Bultman (Naval Research Laboratory, Department of the Navy, Washington, DC), early 1970s)

Photo 5.125 The photo shows materials damaged by pholads. On the right is a fragment of an untreated pine block, and on the left is a polyurethane-coated pine block after 30 days' exposure in Panamanian waters. Numerous trough holes are seen on the untreated pine wood, whereas the polyurethane coating is slightly damaged. The experiment was performed to look for a replacement for Irish felt, a fibre-impregnated bituminous material used between the main hull of a minesweeper and its outer wooden sheathing (this type of a vessel was built of wood so that it could not possess magnetic properties). Nevertheless, the study was restricted only to the experiment, and polyurethane coating was not used later to build minesweepers (Photo credit: J.D. Bultman (Naval Research Laboratory, Department of the Navy, Washington, DC), 1968)

The presence of wood borers and their damaging activity depends on the following *factors* (Ilyin 1992): (1) depth (they inhabit shallow waters mostly, but some species can live at depths of up to 7,000 m), (2) water temperature (the most important determinant of species composition, time of settlement of animals and rate of wood destruction, which is maximal in warm seas), (3) salinity (low salinity is often an obstacle to borers settling on wood), (4) water pollution (creates limitations for borer distribution and their activities) (5) drying out of wood (detrimental for borers, but the duration of their survival in air varies for different species, between 1 and 27 days) (6) ice (helps borers to occupy wood) and (7) water-current speed (even a weak flow hinders borers from settling on wood).

The *most significant of bivalve borers* are representatives of the Teredinidae family (sometimes called the 'termites of the sea' or *shipworms*) and *piddocks/angelwings* (Pholadidae). Wood-boring clams drill into wood with their small shells, built of two-toothed blades on the front of the worm-like body.

Larvae of shellfish borers settle on wood and bore into it. The *size* of the bored inlet is 0.3 mm, and it stays almost the same, but the clam itself grows quickly in the wood, reaching a length of 76 cm in mid-latitude waters and 180 cm in the tropics (Tarasov 1943). The *rate* of wood destruction by the shellfish is *extremely high*. For example, they can destroy a pier piling structure in 2–3 months during the summer (Ilyin 1992).

Crustacean borers comprise more than 20 species, and the most dangerous are the isopods from the family Limnoriidae. These are small crustaceans with body lengths less than 1 cm. They make many small holes in the wood (a few millimetres in diameter and up to 10 cm long). They make them parallel to the wood surface (usually 1–2 cm under the surface). The rate of wood destruction is relatively slow and does not exceed 2 cm/year (Ilyin 1992).

Marine wood borers are dangerous for such *structures* as (1) ship hulls, (2) waterworks and (3) submarine cables. Wood borer damage to ships has been known for ages. In ancient times, the 'shipworms' were called the 'navigator's horror'. The most famous cases are the severe damage inflicted by 'shipworms' to a Crusader fleet in 1200 and to British and French fleets during the siege of Sevastopol in 1854–1855 (Ilyichev et al. 1987).

Although wood is rarely used in the construction of ship hulls anymore, it is still applied quite widely for *hydraulic structures*. Wet, soaked wood does not decay in seawater and may stay preserved for a very long time; however, it is exposed to the action of wood borers.

Publications provide ample evidence of *catastrophic consequences* to *waterworks* of malicious marine wood borer infestation. For example, there was a mass

Photo 5.126 The photo shows a timber section with internal damage caused by a marine borer (*Teredo*). This timber was exposed to marine borers at the US naval station in Honolulu, Hawaii; then it was lifted out of the water and split into two sections. White marks are calcareous sedimentation on the walls of teredo marks. Damage is seen to decrease drastically from the periphery to the central part of the timber section (Photo credit: J.D. Bultman (Naval Research Laboratory, Department of the Navy, Washington, DC), November 1982)

attack by 'shipworms' on wooden structures off the port of Grigorievsky (Black Sea), where log pile piers and bottom gillnet poles were destroyed in a single season in the summer of 1951 (Ilyin 1992). Wood-boring shellfish caused extensive damage to the ports of Tuapse, Gagra, Sukhumi and Batumi, where pier piles 25–30 cm in diameter were destroyed in 1 year (Ryabchikov 1957).

Submarine cables are affected only by xylophagous (diet consists primarily of wood) bivalves. These animals live at depths of up to 7,000 m. Their size does not exceed 2–3 cm. Xylophagous bivalves are repeatedly found in submarine cable insulation, which they damage (Ilyichev et al. 1987).

Damage from marine wood borers on cables is also significant. Shipworms (*Teredo navalis*) alone cause US$205 million in *losses* in the United States annually (Pimentel et al. 2001).

The influences of marine wood borers on human activities are illustrated by Photos 5.124–5.126.

5.12.9 Rock-Boring Organisms

Marine rock borers are a group of marine organisms that damage stone materials, corals, shells and similar materials. Stone-boring organisms are widespread in all seas and oceans. Rock borers may drill by using a mechanical mechanism, a chemical mechanism, or combined mechanisms.

Mechanical drilling also has different mechanisms. *Molluscs* produce abrasion against stone generally with the dorsal surface of their valves. *Octopuses* drill holes with their lingual ribbon (radula), which is a flexible plate with teeth, positioned on the tongue. *Sea urchins* crush rocks and stones with their needles (spines). Sea urchin larvae settle in small rock depressions, the surf spins them in the hole, and their needles abrade the rock surface, increasing the room for the urchins to grow. The average speed of such drilling is about 1 mm/month. Some sea urchins also bore holes with their needles and teeth.

The mechanisms of *chemical drilling* are also quite diverse. The boring sponge of the genus *Cliona* destroys lime substrates with amoebocytes. They secrete substances that corrode calcium. Some bryozoans and algae emit phosphoric acid. Bivalve shellfish or 'marine dates' (*Lithophaga lithophaga*) bore using glandular acid secretions.

Some marine rock borers use a *combined method* of drilling. Some species of 'marine dates' practise mechanical drilling by opening their valves in addi-

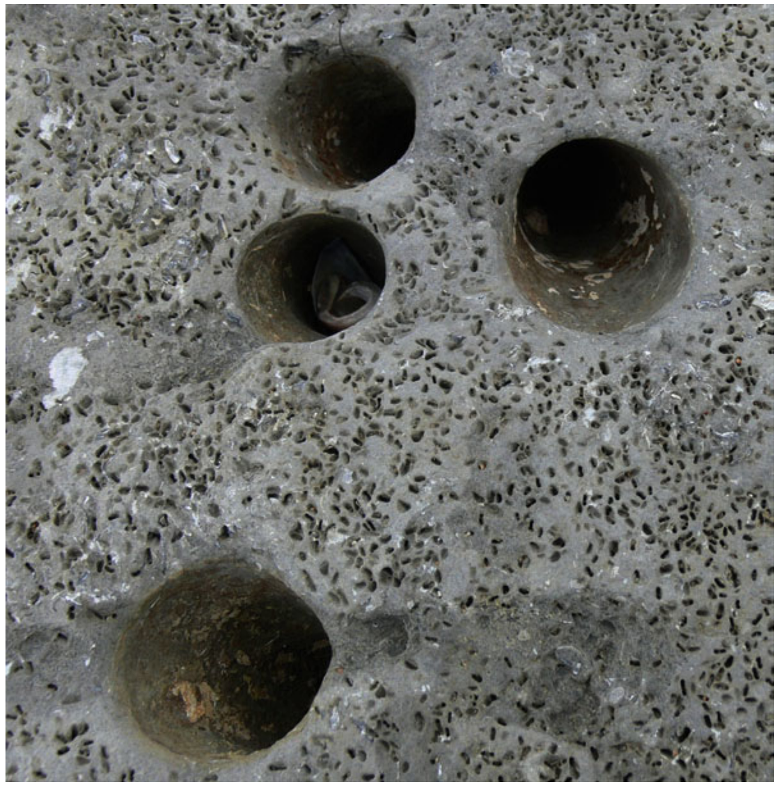

Photo 5.127 Rock-boring organisms are widespread in all seas and oceans. Bivalve molluscs are the most significant rock borers. Openings with diameters of a finger drilled by dactyls in limestone (French shoreline) are shown (Photo credit: http://en.wikipedia.org/wiki/File:Pholades_niches.jpg)

tion to excreting substances that are corrosive to calcium. A number of barnacles use their small teeth in addition to secreting coal anhydrase and alkaline phosphatase as substrate softeners. Similarly, sea worms (Sipunculida) soften hard rocks with epidermal gland secretions and use mechanical abrasion with their bulged back shields and epidermal saws (Ilyichev et al. 1987). Bristleworms (*Lisidice ninetta*, *Polidora ciliata*, *P. websteri* and *P. socialis*) build larval pipes, and then, drill the rock using a sour secretion of their abdominal glands. Then, they clean the drilled holes and mechanically drill on acid-resistant substrates with their bristles (Lebedev 1992).

Bivalve molluscs are the most *significant rock borers* in terms of their impacts on human activities. Boring sponges or clions (Clionidae) and echinoderms (sea urchins) are also important. Basically, rock borers cause damage to the following *objects*: (1) waterworks, (2) submarine cables and (3) aquaculture structures (shellfish nurseries).

The most dangerous destroyers of *waterworks* are bivalve molluscs, especially '*sea drills*' (e.g. *Pholas dactylus*). These are large (up to 15 cm) molluscs that live at depths of up to 500 m. Their shell valves are connected by muscles, and the outer front side of their shells is covered with denticles, resembling the surface of a file. They ream their way inside with alternating rocking movements of the valves. Over a 2 year period, these rock borers can drill a course in a rock up to 24 cm long (Biological encyclopaedic dictionary 1986).

There are numerous *examples* of the impacts of foladid (Pholadidae) bivalves on waterworks. They damaged the massive concrete lock gates of the Panama Canal; the bricks of docks in Calcutta (India) and the concrete coating of wooden piles in San Francisco (Tarasov 1943). T.K. Jadkowski and E.A. Wiltsie (1985) described the rapid disintegration (over 10–15 years) of cylindrical concrete piles installed in the Arabian Gulf; the damage was caused by rock-boring molluscs and sponges.

Sea urchins are other organisms that damage waterworks. There are records that one of them, the California purple sea urchin (*Strongylocentrotus purpuratus*), drilled even steel piles in California.

Damage to *undersea cables* is caused by the activities of some bivalve species. They settle in cable sheathing, destroying it and causing electric current

Photo 5.128 This image of a dried oyster shell (*Crassostrea virginica*) shows the yellow sponge tissue (*Cliona celata*); the holes the sponge creates for incurrent and excurrent pores; and the extensive gallery space excavated (Photo credit: N. Lindquist, University of North Carolina (United States))

leakage. This is especially dangerous for deep-lying cables, which are extremely difficult to repair (Ilyichev et al. 1987).

Rock borers cause significant damage to *aquacultural structures*. The most important one is the boring sponge of the genus *Cliona*. For example, in Bogue Sound and the Newport River estuary (North Carolina, United States), they caused great damage to oyster farms. Field surveys found up to 68% of the oyster shells had these boring sponges (Hale 2009). Boring by sponges decreases oyster marketability and is hypothesized to increase shell fragility and oyster mortality and decrease overall oyster health. There is a similar situation with boring sponges at oyster farms in the Black Sea (Preobrazhensky 1986).

The impacts of rock borers on human activities are illustrated by Photos 5.127 and 5.128.

5.13 Natural Fires

Natural fires are characteristic of all continents except Antarctica. Many terrestrial biomes are subject to natural fires; for example, forests, savannas, grasslands (pampas, veldts, steppes and prairies) and shrublands (chaparral, scrub, espinal and maquis). Their total area is from 78 to 89 million square kilometres, according to different data.

Australia, the United States, Brazil, France, Spain, Greece and India suffer from natural fires to the *greatest extent*. Annually, approximately 400,000 natural fires emerge in the world. The average annual area of natural fires on the Earth is estimated at 700,000–800,000 km^2 (Govorushko 2009c). The global distribution of natural fires is shown in Fig. 5.40.

Any fire begins and develops under a simultaneous combination of *three basic conditions* (Nabatov 1997): (1) presence of combustible materials, (2) presence of a source of fire and (3) favourable weather conditions. Combustible materials are objects such as trees, scrub, grass, ground wood and soil cover.

Sources of fire can be natural, anthropogenic and of mixed origin. The *natural sources* of fire are (1) *lightning* (it accounts for 20,000–50,000 fires; the average density of lightning strikes depends on region and varies from 5 to 50 strikes per square kilometre per year; in different regions they trigger from 0.17% to 84% of all natural fires), (2) *volcanic eruptions* (an average of 50 volcanoes erupt every year, and the danger is mostly presented by lava flows and burning volcanic clouds), (3) *meteorites* (according to different data, in an area of one million square kilometres, 50–100 meteorites

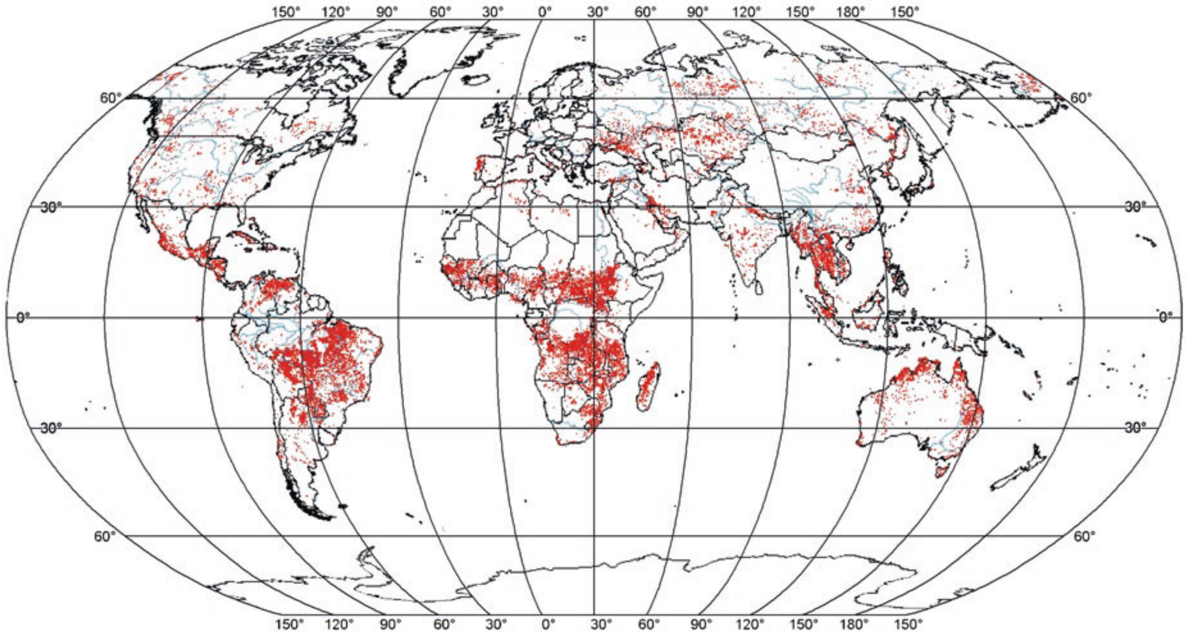

Fig. 5.40 Global distribution of fires (Reproduced with permission of European Space Agency. The ESA global detection of hot spots by ERS-2's Along Track Scanning Radiometer (ATSR-2) and Envisat's Advanced Along Track Scanning Radiometer (AATSR) in 2005. These twin radiometer sensors work like thermometer in the sky, measuring thermal infrared radiation to take the temperature of Earth's land surfaces. Temperatures exceeding 312 K (38.85°C) are classed as burning fires)

Photo 5.129 Many terrestrial biomes are subject to natural fires; for example, forests; savannas; grasslands (pampas, velds, steppes, prairies); and shrublands (chaparral, scrub, espinal, maquis). The photo shows a fire in a cordgrass (*Spartina* spp. Schreb.) marsh in the United States (Photo credit: Dale Wade, Rx Fire Doctor, Bugwood.org)

Photo 5.130 One of the natural sources of fires are lava flows. The photo shows a lava stream that flows through a forest on Hawaii. The lava stream is about 3 m wide (Photo credit: US Geological Survey)

Photo 5.131 Atmospheric haze has the most important effect of fires on people's health. A smoke cloud from a forest fire can spread large distances. It creates mass problems for people's respiratory and cardiovascular systems, eye irritation and aggravation of allergies. The photo shows a smoke column formed during the South Hollow fire (spruce-fir-aspen) in August 2001 in Uinta National Forest, Utah (United States) (Photo credit: Doug Page, USDI Bureau of Land Management, Bugwood.org)

Photo 5.132 One of the consequences of forest fires is deterioration of the aesthetic attractiveness of landscapes, which can affect recreational activities. The photo shows a burned area in the Korean pine forest (Terneisky district, Primorsky Krai, Russia) (Photo credit: A.M. Panichev, Pacific Geographical Institute, Vladivostok, Russia, November 1982)

fall on the Earth annually that are heavier than 100 g; i.e. from 25,500 to 51,000), (4) spontaneous *ignition* of natural materials (usually vegetative rests, generating warmth during rotting and fermentation) and (5) *sparks* created by rockfalls and landslides.

Sources of fires of *anthropogenic origin* include things such as the following: (1) unextinguished *matches* and cigar butts, (2) *unextinguished fires*, (3) *sparks* from functioning engines, (4) agricultural *grass fires*, (5) smouldering of hunting *wads* after a shot, (6) blowing-up of *stumps*, (7) *childish antics* with fire and (8) *deliberate arson*.

Sources of *mixed origin* include the following: (1) *self-ignition* of oily rags and (2) *splinters* of bottles focusing solar beams. Meteorological factors influencing fires are (1) precipitation, (2) air temperature, (3) relative humidity and (4) wind speed.

Negative consequences of fires include (1) human deaths and structural damage, (2) negative influences on human health, (3) complication of transport and (4) decreases in the recreational value of areas affected.

More than a few cases of *catastrophic forest fires* leading to massive loss of life and destruction of buildings are recorded in world history. The fire that occurred on 8 October 1871 in the brush near the town of Peshtigo (Wisconsin, United States) spread over an area of 486 ha, totally destroying the town. Another 16 cities and towns were partially damaged, and the total number of victims amounted to 1,200 persons (www.fs.fed.us/fire/nfp/president.shtml). In Australia in 1939, forest fires destroyed 600 homes and 67 sawmills (Stojko and Tretyak 1983). In southern Australia, on 16–17 February 1983, fires burned about 2,000 houses and killed 20,000 head of cattle and 71 people (Myagkov 1995).

Atmospheric haze has an important effect on people's health. A smoke cloud from forest fires spread over western and central Siberia in 1915, covering an area equal to that of Western Europe (Kovalevsky 1986). At least 30 million citizens of Russia were in the zone of intensive and lengthy (sometimes up to several months) smoke in the summer of 2002 (Grigoryev 2003). There were mass problems noted with people's respiratory and cardiovascular systems, eye irritation and aggravation of allergies.

Twenty million people were exposed to *respiratory diseases* as a result of combustion products created during fires in Southeast Asia in 1998. The damage to their health is estimated at US$1.4 billion (Natural and anthropogenic processes 2004). *Gas emissions* also have made a significant contribution to negative health effects. For example, wildfires yielded the following percentages of emissions in the United States during 1970–1976 (Smith 1985): carbon monoxide, 4%; particulate matter, 3%; hydrocarbons, 2% and nitrogen oxides, 0.6%.

Complication of transport operations is largely due to smoke formation. Several sites along the Trans-Siberian railway were closed to traffic during the Siberian fires in 1915 (Stoiko and Tretyak 1983). Visibility dropped to 50–100 m at times as result of fires near Moscow in 2002, which created problems for road and rail transportation. Air traffic was also affected. Numerous flight delays occurred periodically, aircraft were redirected to other airports, and even landing accidents occurred (Grigoryev 2003). Recreational activities were damaged due to deterioration of the aesthetic attractiveness of landscapes.

All together, these effects lead to large *economic losses*. Total losses amounted to at least US$600 million from catastrophic fires in north-eastern Florida (United States) in June–July 1998 (Butry et al. 2001). Average direct economic losses are hundreds of millions to billions of dollars because of forest and grassland fires in the world (Natural and anthropogenic processes 2004). Similar damage in India is estimated at 440 million rupees; that is, approximately US$97.8 million (Mikhopadhyay 2006). It should be noted that most of the damage relates to large fires: they average only approximately 1% of the total number of fires but cause approximately 90% of the damage (Valendik et al. 1979).

The effects of fires on human activities are illustrated by Photos 5.129–5.132.

5.14 Environmental Allergens

Allergy is a phenomenon of excessive sensitivity of an organism to foreign substances, which are called *allergens*. Allergic diseases are widespread. According to various sources, they affect 10% (Pytsky et al. 1991), 17–20% (Veltischev and Svyatkina 1995), 20% (Neffen 2003), 30–40% (Clinical allergology 2002), or 50% (Zavgorodnaya et al. 2000) of the world's human population. In any case, the percentage appears to have increased over the past decades. Also, there are significant variations in magnitude, from 1% to 50% or more in various countries or regions, and among certain groups in the population. It is believed that the number of people with allergic diseases *doubles* every 10 years (Luss 2003).

Allergens are divided into the following groups according their *mode of transmission* into an organism: (1) air allergens (pollen, animal hair, epidermis, etc.), (2) food allergens, (3) contact allergens, which penetrate through the skin and mucous membranes (chemicals and drugs), (4) injection allergens (whey and drugs), (5) infectious allergens (bacteria and viruses) and (6) allergenic medicines (Pytsky et al. 1991).

Allergens are also divided into several *categories* based on their *origin*: (1) household (primarily house dust), (2) epidermal (wool, feathers, dander, faeces and pet's saliva), (3) insects (synanthropic mites, cockroaches, biting and bloodsucking insects and arachnids), (4) pollen (pollen of various plants), (5) food, (6) drugs (allergic reactions may be caused by any medication, including anti-allergic agents), (7) fungi (mostly moulds and yeast) and (8) helminths (ascarid antigens, pinworms, trichurids and other helminths).

Economic losses due to allergic diseases are very high. They consist of direct treatment costs, loss of work and school days, reduced productivity, increased accidents due to taking sedative antihistamines and others. For example, 811,000 working days and 824,000 school days are lost due to allergies in the United States every year; 4.2 million days are characterized by decreased activity. In total, the cost of allergic diseases is US$18 billion a year for the United States health care system (A closer look at allergies 2001). In Europe, the direct costs of treatment are up to 1–1.5 billion Euros a year, and indirect costs are another 1.5–2 billion Euros (Second congress of allergists 2006).

In *Australia*, 4.1 million inhabitants (19.6% of the population) suffer from at least one allergic disease. Many highly allergic sufferers are prone to other diseases also, so the average ratio is 1.74 allergy per person. The 'costs' of allergies were estimated at US$7.8 billion in this country in 2007; major components of damage were reduced productivity (US$4.2 billion) and direct medical costs (US$1.2 billion). It has been suggested that the number of Australians with allergies will increase to 26.1% by 2050 (The economic impact of allergic disease in Australia 2007). In various regions of Russia, the prevalence of allergic diseases varies from 15% to 35% (Ilyina and Fedoskova 2004).

With few exceptions, manifestations of allergic diseases fit into *four main syndromes* (Pukhlik 2002): (1) chronic rhinitis, (2) shortness of breath (dyspnea), (3) itchy skin rashes, and (4) anaphylaxis. Allergens that cause these manifestations are many. This section will deal primarily with natural allergens, which can be of plant or animal origin.

5.14.1 Allergens of Plant Origin

Allergens of plant origin include tree and grass pollens, spores of microscopic fungi and biologically active substances of some plants that are able to sensitize skin (i.e. increase its sensitivity) on direct contact. Such plants can cause allergic *contact dermatitis*.

Allergy to pollen is called *pollinosis*. To invoke it, pollen should possess the following *properties*: (1) produced in large quantities, (2) sufficiently light to be carried by wind over long distances, (3) have dimensions that allow it to penetrate into the respiratory tract, (4) belong to common plants in an area and (5) have expressed allergenic properties (Ziselson 1986).

For an allergic response to develop, a person must inhale at least 500 pollen grains, and their concentration must be at least 25 grains per cubic metre of air (Pukhlik 2002). The *distance ranges* of pollen of various plants are very different. For example, Norway spruce (*Picea abies*) pollen is distributed an average of 22.2 km from it source, at a wind speed of 10 m/s, while the average radius of alder (*Alnus*) pollen scatter is 546.7 km (Smith 1985). For pollen penetration into the respiratory tract, the particles must have a diameter under 35 μm (Ado and Astafyeva 1991).

The *allergenic properties of pollen* depend on characteristics such as the following: (1) the nature of the grain surface (grains with rough surfaces are more likely to produce allergies), (2) their age (fresh pollen is more harmful) and (3) weather conditions under which the pollen is produced (activity of pollen grains is higher with low humidity and high temperatures).

There are several hundred species of plants whose pollen causes pollinosis. For example, there are over 200 species of allergenic plants in the United States, and a similar list for Mongolia includes 203 species (Sangidorzh 2004).

The most usual *clinical manifestations* of pollinosis are: (1) seasonal allergic rhinitis (characterized by disorders of nasal breathing, sneezing, itchy nose), (2) conjunctivitis (manifested by itching eyelids and eyes, and redness), (3) allergic pharyngitis (sensation of mucus dripping from the back of the throat and itching and soreness in the lower oesophagus), (4) otitis (ear infection), (5) pollen asthma (attacks of dry cough, often with difficulty exhaling), (6) cutaneous manifestations of pollinosis (atopic dermatitis, urticaria, eczema, etc., which occur in approximately 6% of patients) and (7) enteritis (i.e. inflammatory disease of small intestinal mucosa) (Pukhlik 2002).

From 0.2% to 39% of the population suffer from pollinosis in various countries around the world (Peredkova 2009). The prevalence of pollen allergy depends on climatic, ecological, and ethnographic factors. For example, pollinoses are *extremely rare* in the indigenous people of Japan, Mongolia, Brazil and South Africa.

The *highest rates* of pollinosis are characteristic of Mexico and the United States. Other countries with high rates include India, France, Sweden and Belgium, among others. In general, residents of the western hemisphere suffer from it more often than those of the eastern hemisphere (Great medicinal encyclopaedia, vol 20 1983).

There has been a permanent rise in pollinosis *morbidity*. For example, its prevalence was only 1% in Switzerland in 1926, whereas it was 4.4% in 1958; 9.6% in 1985 and 13.5% in 1993 (Wurthrich et al. 1995).

The most important allergenic plant is *common ragweed* (*Ambrosia artemisiifolia*). The global distribution of common ragweed is shown in Fig. 5.41. For example, its pollen causes pollinosis in 4% of the population in the United States (Maryushkina 1986). The most vulnerable people are in the states of Georgia, Indiana and Oklahoma (Sangidorzh 2004). In France and Belgium, pollinosis due to common ragweed is also widely known; it affects up to 18% of the total number of patients with pollinosis (Ado and Astafyeva 1991). In France it affects approximately 540,000 inhabitants; that is, almost 1% of the population.

Approximately 200 million people suffer from pollinosis worldwide, with relative *economic losses* estimated at US$8–10 billion per year.

With regard to *fungal allergens*, there are more than 100,000 known species of micro-fungi. About 300 of

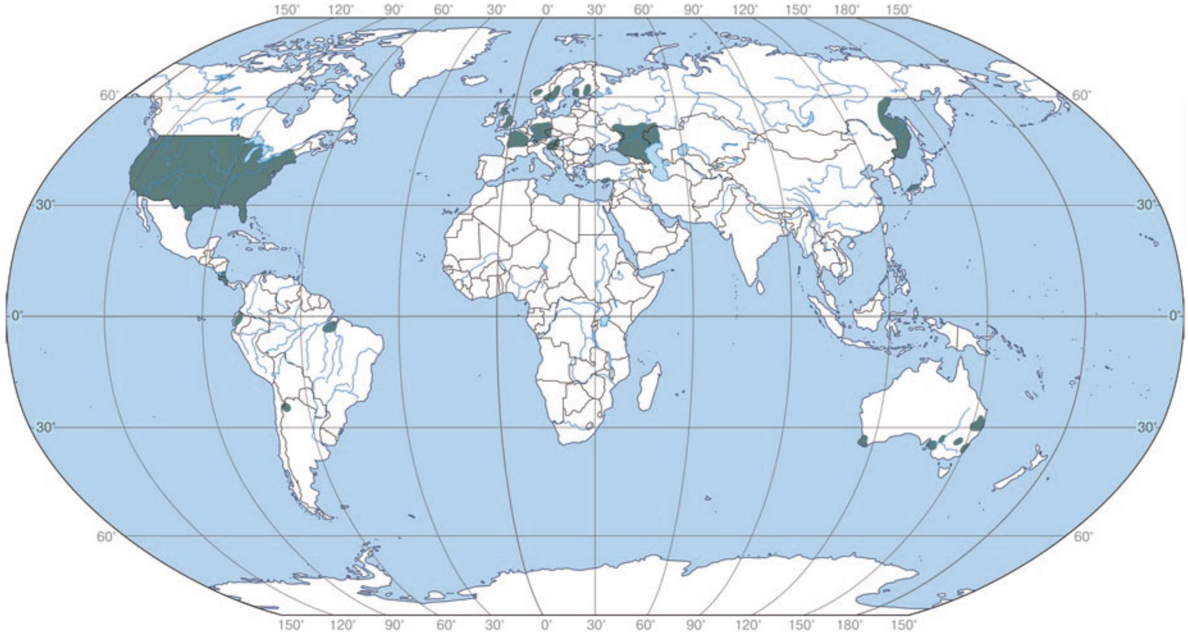

Fig. 5.41 Global distribution of common ragweed (*Ambrosia artemisiifolia* L.) (Adapted from: http://sevin.ru/invasive/invasion/plants/ragweed.html; http://www.europe-aliens.org/speciesFactsheet.do?speciesId=21692#; http://data.gbif.org/species/13749043/;http://plants.usda.gov/java/profile?symbol=AMAR2)

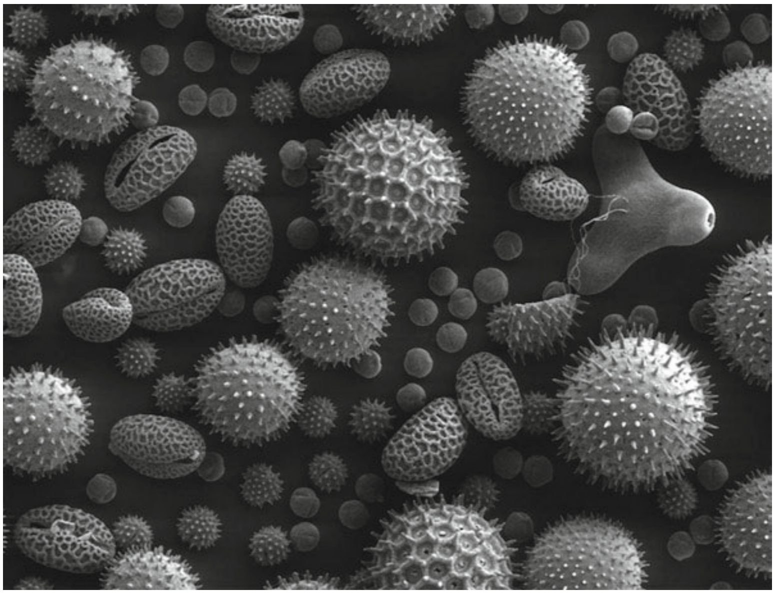

Photo 5.133 The allergenic properties of pollen depend on different characteristics (the nature of the grain surface, their age, weather conditions, etc.). The photo shows pollen from a variety of common plants: sunflower (*Helianthus annuus*); morning glory (*Ipomoea purpurea*); hollyhock (*Sildalcea malviflora*); lily (*Lilium auratum*); primrose (*Oenothera fruticosa*); and castor bean (*Ricinus communis*). The image is magnified some 500 times, so the bean-shaped grain in the bottom left corner is about 50 micrometres long (Photo credit: Dartmouth Electron Microscope Facility, Dartmouth College)

Photo 5.134 The most dangerous plants that cause allergic contact dermatitis are representatives of the genus *Toxicodendron* of the cashew family (Anacardiaceae). These plants cause allergic reactions in the majority of people. The photo shows blistering resulting from contact with poison ivy (*Toxicodendron radicans*) (Photo credit: http://en.wikipedia.org/wiki/Urushiol-induced_contact_dermatitis)

them are capable of sensitizing humans (Leksakov 2006), and there are approximately 100 species that people actually come into contact with. Mould fungi, or just moulds are the most common allergy-causing fungi. The most significant representatives that cause respiratory allergy are of the genera *Aspergillus*, *Penicillium*, *Alternaria* and *Cladosporium* (Fedoskova 2007). Currently, fungal spore allergies are referred to as pollinosis in most countries around the world.

Allergic contact dermatitis is an inflammatory skin lesion that develops at the point of allergen contact in highly sensitive organisms. Usually, allergic dermatitis occurs on exposed areas of skin directly affected by the irritant and does not extend beyond. From 5% to 10% of the world's population suffer from it (Lomonosov and Ignatyev 2007), but only a small part of the disease is caused by plants.

The development of allergic contact dermatitis can be caused by plants from the following *families*: (1) cashew/sumac family (Anacardiaceae), which will be discussed separately; (2) sunflower family (Asteraceae/Compositae), particularly plants of the genus *Tagetes* (marigolds); (3) onion family (Alliaceae); genus *Allium* includes many varieties of onion and garlic; they are one of the causes of fingertip dermatitis in homemakers, food handlers and vegetable suppliers; (4) lily family (Liliaceae); there is the known syndrome 'tulip fingers', an allergic contact dermatitis caused by contact with tulip bulbs, which affects fingers of the dominant hand; (5) mint family (Lamiaceae), espe-

Photo 5.135 Contact dermatitis can be also caused by ordinary yard (garlic, onion, carrot and celery) and garden (chrysanthemum, daisy, narcissus, primrose, etc.) plants. The primrose is shown here (Photo credit: New Zealand Dermatological Society)

Photo 5.136 In case of allergic contact dermatitis, the body surface part directly contacting the inciter of the allergy (more often, hands and lower arm) is affected. A dermatitis caused by contact with primrose is shown (Photo credit: New Zealand Dermatological Society)

cially mint, lavender, sage and thyme; (6) primrose family (Primulaceae); primrose contains the allergen primin, which causes dermatitis of the fingertips and sometimes the whole hand and (7) the pine family (Pinaceae); the most common tree species to cause contact dermatitis (http://www.alergolog.ru/clauses/contactdermaty).

The *most dangerous plants* that cause allergic contact dermatitis are representatives of the genus *Toxicodendron* of the cashew family (Anacardiaceae). These plants cause allergic reactions in the majority of people.

The most famous of them are *poison ivy* (*Toxicodendron radicans*); two species of *poison oak* (*Toxicodendron diversilobum*, which grows on the West Coast of North America and *Toxicodendron pubescens*, which grows in the eastern United States) and *poison sumac* (*Toxicodendron vernix*). In the United States alone, poison ivy, poison oak and poison sumac cause over 350,000 skin poisonings per year in total (http://citomedicine.ru/vozdejstvie-yadovitogo-plyushha-duba-i-sumaxa.html).

The effects of allergens of plant origin on human activities are illustrated by Photos 5.133–5.136.

5.14.2 Allergens of Animal Origin

The main sources of *allergens of animal origin* are insects. Allergenic insects are divided into two large *groups* (Fedoskova 2007): (1) stinging and (2) non-stinging. In turn, non-stinging insects fall into the following groups: (1) non-biting, (2) biting and (3) bloodsucking.

Possible *ways* that insect allergens get into the body include the *following* (Pytsky et al. 1991): (1) poison in stings, (2) saliva in bites and (3) inhalation and contact with body scales or dust from insect bodies.

Allergy to stinging insects dominates, reaching 8% of all allergic reactions in some countries (Fedoskova 2004). Here, the *most dangerous* are bees, wasps, hornets, ants, etc. Allergic reactions to stings are *divided* into local and systemic.

Local allergic reactions are characterized by severe itching, swelling and redness at the stinging site, which lasts for at least 24 h. *Systemic* allergic reactions are detected in 0.8–5% of the population and constitute 77% of allergic reactions to hymenopteran (Hymenoptera) venom. The most severe form is anaphylactic shock. It develops in a few seconds or minutes after a sting and sometimes ends in death.

Based on *timing*, there are early and late allergic reactions to stings. Early reactions begin immediately or during the first hour; they make up to 95–98% of cases. The late reactions develop 6–12 h after a sting, and they account for 2–5% of reactions (Pukhlik 2002).

Allergies due to contact with *saliva in bites* are characteristic mainly of bloodsucking insects (mosquitoes, flies, gnats, lice, bedbugs and fleas). Allergic reactions are usually *local* in nature. They generally occur after 6–12 h, picking up within 48 h and sometimes continuing for up to 2 months. No cases of

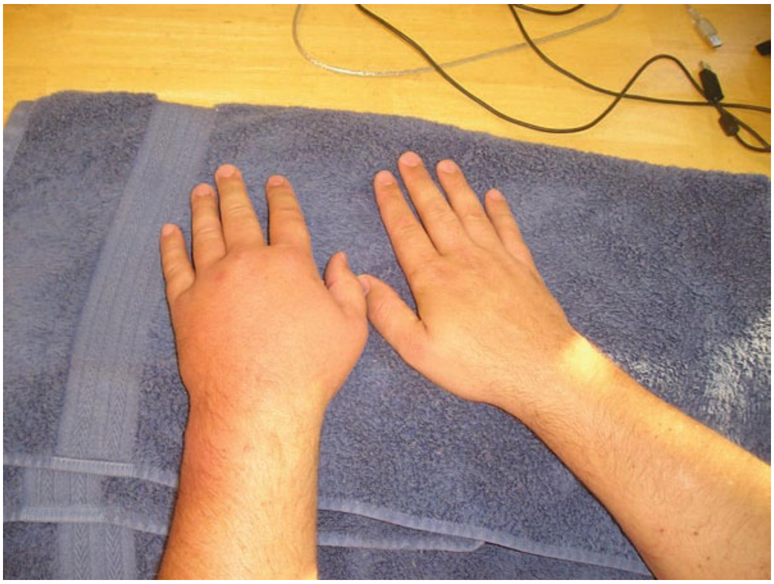

Photo 5.137 Allergy to stinging insects dominates, accounting for 8% of all allergic reactions in some countries. Among stinging insects, the most dangerous are bees, wasps, hornets, ants, etc. The photo shows an allergic reaction 2 days after a paper wasp sting (Photo credit: Joseph Frazier)

anaphylactic shock from the bites of bloodsucking insects are known (Pytsky et al. 1991).

Inhalation and *contact* allergies are caused mainly by representatives of the order Lepidoptera (butterflies, moths) and caddis flies (Trichoptera). For example, outbreaks of allergic respiratory system diseases have been recorded in people living near water during the period of caddis fly mass reproduction in North America.

True flies (Diptera) are a less frequent cause of these reactions. Mosquito larvae, or 'wigglers', cause rhinitis and conjunctivitis among aquarists. Protocockroaches (order Blattoptera) cause allergy in patients with bronchial asthma. Grasshoppers and crickets (order Orthoptera) are sources of allergy; well-known cases are associated with locusts in Australia. Bees (order Hymenoptera) cause asthma and contact dermatitis in beekeepers.

The *death* of the first ruler of the two Nile Kingdoms, the Egyptian Pharaoh Menes, is the earliest known case of death from anaphylactic shock. In most cases, death occurs relatively fast: 59–92% of victims die within the first hour, according to various sources and 81–96% in the first day. There are significant *variations in mortality* rates in different countries: England and Wales have 0.09 deaths per one million residents; the United States, 0.14; Germany, 0.18; Denmark, 0.25 and Switzerland, 0.45 (Mueller 1990). Calculations based on these data indicate a global mortality rate of about 1,000–1,200 people per year.

Approximately two million Americans have *allergic reactions* to stinging insects (http://www.aafa.org//templ/display.cfm&id=304&sub=98). Between 40 and 50 victims *die* each year as a result of allergic reactions to the venom of hymenoptera in the United States (Reisman 1998), 10–25 in France, and 10–40 in Germany. The sting of the Asian giant hornet (*Vespa mandarinia*) results in more human deaths, each year in Japan, than those due to all other venomous and non-venomous wild animals combined.

Indirectly, allergens of animal origin also affect the workers of the livestock and textile industries. The impacts of *livestock rearing* on humans can be seen in *stock-keeper's asthma*, which is caused by inhaling particles of wool and skin of animals. Horse epidermis is one of the strongest allergens (Pytsky et al. 1991).

Workers involved in the production of natural silk contract asthma and impact the *textile industry*. Pollen covering the wings of butterflies and moths is a strong allergen. Air in factories is heavily saturated with dust, consisting of scales of the bodies and wings of butterflies, which are liberated during their mass exit from cocoons. At this time, massive outbreaks of allergic diseases of the respiratory tract occur, affecting from 75% to 98% of employees (Pytsky et al. 1991).

The effect of allergens of animal origin on human activities is illustrated by Photo 5.137.

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6 Biogeochemical Processes

Abstract

Biogeochemical processes include those in the Earth's biosphere (shell of the Earth, including the atmosphere, hydrosphere, and upper part of the lithosphere [Earth's crust]) which occur with the participation of living organisms. Selective absorption of chemical elements in accordance with their physiological needs leads to biogenic differentiation of organisms in the environment. A biont is mortal, but life in the form of continued generations is eternal. The effect of organisms on the environment has lasted about four billion years without interruptions. Despite the fact that living organisms are an insignificant part of the mass of the outer shells of the Earth, the total effect of their geochemical activity, with regard to the time factor, is of great planetary importance. The formation of sedimentary rocks results from the activity of living organisms, and metamorphic rocks, minerals, Earth's landscapes, and the atmosphere are formed with the partial participation of living organisms.

Keywords

Economic loss • Mortality • Disease • Origin conditions and mechanism • Impact on human activity

6.1 Salinization of Soils

Salinized soils are soils with a content of easily soluble salts in amounts that degrade soil fertility and have adverse impacts on the growth and development of most plants (Natural and human induced salinization of soils 1996). Soils are considered to be salinized if they contain more than 0.1% (by mass) of salts toxic for plants (Nikolaikin et al. 2003).

Saline soils are *widely distributed* on all continents, and they occur in 100 countries of the world. They are found in practically all natural zones but undoubtedly prevail in the steppe, semi-desert, and desert zones. The *total area* of saline soils in the world is more than 950 million hectares, including (in thousand hectares) the following: 17,720 in North America; 129,165 in South America; 80,538 in Africa; 84,971 in south and west Asia; 211,448 in north and central Asia; 21,521 in Southeast Asia; 357,568 in Australia and Oceania; and 50,804 in Europe (Saline soils of Russia 2006).

The *primary sources* of salts are volcanic activity and rock disintegration products. Furthermore, their redistribution and transformation occur on land and sea. As for the origin of salts in soil, in addition to the sources mentioned, there are also *other sources* of their supply. *They include* Aeolian transfer of salts from the seas, fossil salt deposits, biogenic salt accumulation (related to accumulation of salts by plants and subsequent

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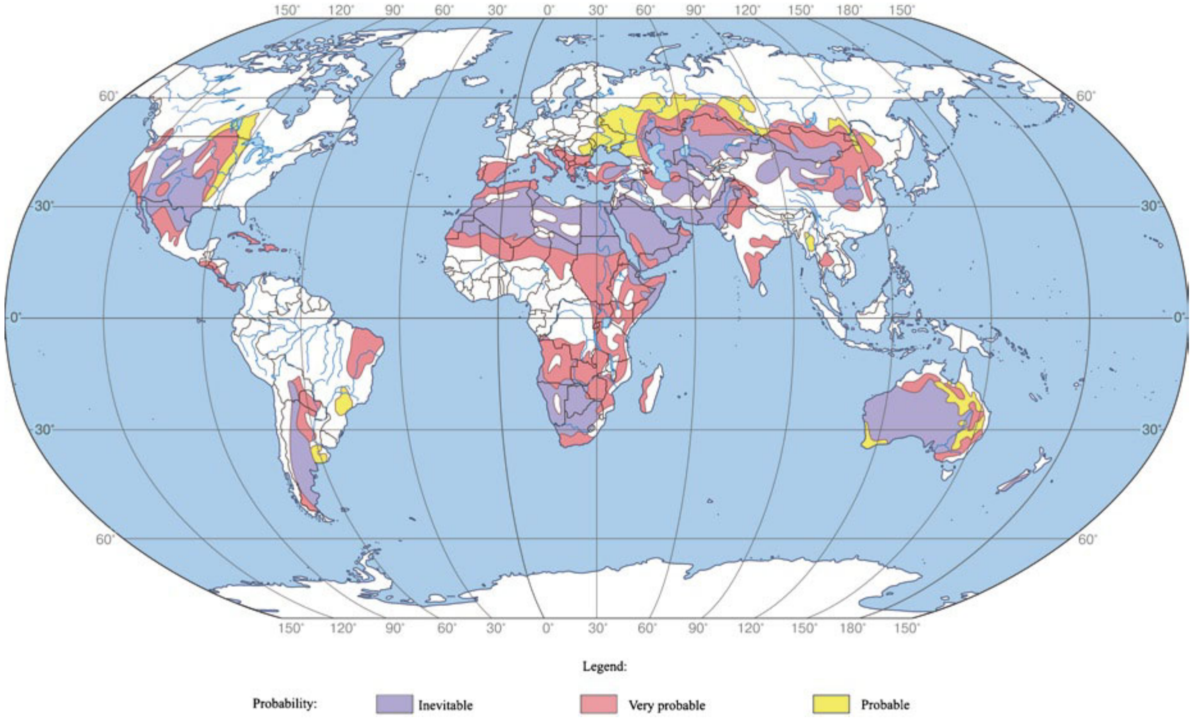

Fig. 6.1 Risk of secondary soil salinization under conditions of non-drainage irrigation (Resources and environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of Sciences)

enrichment of soils with these salts from dead soil cover), and so on (Natural and human-induced salinization of soils in the Aral Sea basin 1996).

The *reasons* for salinization can be divided into five *groups:* (1) poor cultivation techniques; (2) indirect effects of irrigation schemes; (3) vegetation changes; (4) seawater incursion; and (5) disposal of saline wastes (Thomas and Middleton 1997).

Two *kinds* of salinization have been identified: primary and secondary. The *primary* salinization of soils takes place under natural conditions and is caused by such factors as depth below the soil layer and mineralization of underground waters, grain-size classification, soil structure, water exchange, climatic conditions, and so on. The *secondary* salinization of soil results from human productive activities as a result of excessive irrigation and lack of natural or artificial drainage (Glushko 2010). Risk of secondary soil salinization under conditions of non-drainage irrigation is shown in Fig. 6.1.

The primary diagnostic indicators of saline soils *are*: (1) the depth of the salt horizon; (2) composition of salts; and (3) salinization extent or salt stock. Based on the depth of the salt horizon, one can identify the *following*: (1) really saline soils containing salts within the upper root layer of 0–100 cm, including (a) surface saline (alkaline lands) – top roof of the salt horizon is within a layer of 0–30 cm and (b) middle saline (solonchak-like) soils in which salts occur at depths of 30–100 cm; (2) deep saline soils in which the salts are at depths of 100–200 cm; and (3) potentially saline soils where salts are in the underlying rocks (200–500 cm) or in underground waters (Natural and human-induced salinization of soils in the Aral Sea basin 1996).

As for the *composition* of salts, the following soils have been *identified*: (1) soils containing *neutral* salts (sulphates and chlorides), which are called saline soils and (2) soils containing *alkaline* salts (predominantly sodium and magnesium carbonates and bicarbonates), which are called alkali soils. The salinization extent is determined by the concentration of salts in the soil solutions of the upper (0–30 cm) root layer. The *toxicity* levels for different plants vary. For cotton, for

Photo 6.1 Soil resalinization is a challenge for irrigated agriculture in arid areas. An estimated 30–80% of irrigated lands are susceptible to resalinization. Among the major locations of resalinization is the Colorado River basin. Salt-affected soils are visible on rangeland in Colorado. Salts dissolved from the soil accumulate at the soil surface and are deposited on the ground and at the base of the fence post (Photo credit: Tim McCabe, Natural Resources Conservation Service, United States, 1983)

Photo 6.2 Soil salinization results in deterioration of soil structure and in plants losing the capability to take up nutrient materials from soil, strongly reducing the productivity of the land. The photo shows soil salinization in Utah (U.S.) (Photo credit: Ron Nichols, Natural Resources Conservation Service, United States, 1994)

example, salt contents of 5–6, 10–12, and 12–20 g/l correspond to a weak, strong, and very strong stress on the plants, respectively, while plants perish at salt concentrations of 20–25 g/l (Kovda 1984).

Salinized soils differ not only in salt indicators but also in their *other properties*: humus content, hydrophysical and physico-chemical properties, and so on (Saline soils of Russia 2006).

At present, the secondary salinization of soils prevails, caused primarily by *irrigation*. As a rule, irrigation water contains various amounts of salts. When the water is pumped to fields, much of it turns into vapour, and the salts it contains remain in the soil. Their influence on plants is manifested as direct toxicity, soil structure variations, and osmotic pressure changes (Goudie and Viles 1997).

Due to secondary soil salinization, about 0.2–0.3 million hectares of cultivated lands in the world go out of service every year. *Sites* where the problem is the greatest *include* the valleys of the Helmand River in Afghanistan, Mexicali Valley in Mexico, Tigris and Euphrates Rivers in Syria and Iraq, and Colorado and

Imperial Rivers in the United States (Gorshkov 2001; Mavrishhev 2000).

Soil salinization results in abrupt decreases in crop capacity. Even in cases of weak salinization, productivity of cotton and wheat decreases by 50–60% while that of corn decreases by 40–50% (Mazur and Ivanov 2004). At times, it results in complete uselessness of irrigated lands for crop production. This problem is most serious for crop farming in arid areas, especially where irrigation has been carried out since ancient times. For this reason, a large portion of irrigated lands have been put out of action: a *third* of the lands in *Iraq*, a *fourth* in *Pakistan*, a *fifth* in China, and a *sixth* in India. It is believed that salinization of soils alone caused the collapse of Babylon (Gorshkov 2001).

On a *global scale*, an abrupt reduction in productivity has been noted on 100 million hectares of agricultural lands, and about 20–25 million hectares has been completely lost for agriculture (Alekseenko 2005). *Annual losses* caused by soil salinization are US$3 billion (Kovda 1984).

The effects of soil salinization on human activities are illustrated by Photos 6.1 and 6.2.

6.2 Microelementoses

Microelementoses (biogeochemical endemic diseases) are diseases of humans, animals, and plants caused by a lack, excess, or imbalance of microelements. All living beings consist of 12 of the most commonly encountered chemical elements, to the extent of 99%. Another 69 elements are contained in the human organism in very small amounts. Of these, 15 elements (iron, iodine, copper, zinc, cobalt, chromium, molybdenum, nickel, vanadium, selenium, manganese, arsenic, fluorine, silicon, and lithium) are *vital*. An additional four elements (cadmium, lead, tin, and rubidium) are recognised as *candidates* for this list (Microelementoses of humans 1991; Oliver 1997).

The *contents* of the same chemical elements in the rocks of different areas vary. Some regions on the Earth differ from neighbouring ones in the levels of chemical elements, and therefore, different biological responses develop on the part of local fauna and flora. Such regions are called *biogeochemical provinces* (Yermakov 1995).

Sometimes, these differences are significant. For example, soil-forming rocks differ in content of copper by factors of 34–68, in content of zinc by factors of 25–170, in content of boron by a factor of 500, and in content of cobalt by a factor of 2,000 (Endemic diseases of agricultural animals 1990).

Due to weathering, rocks form soils, and these soils contain the chemical elements of the mother material. In the course of their evolution, soils may *accumulate* and also *lose* some elements of the soil-forming rocks. These processes depend on climatic and biological factors, landscape conditions, and so on. In some cases, the correlation of the chemical composition of soils with the composition of soil-forming rocks can be partial or even *absent* (Kovalsky 1974).

In the soils that are formed, *variations* in the composition of individual elements are much greater. For example, the content of *copper* can differ by a factor of 1,500. Great differences in concentrations of individual macro- and microelements are also characteristic of water. Waters differ from each other by a factor of 30 in the content of *boron*, a factor of 40 for *copper*, a factor of 100 for *strontium*, a factor of 200 for *zinc*, and a factor of 300 for *cobalt* (Endemic diseases of agricultural animals 1990).

On Earth, regions with abnormally low and high concentrations of elements in soil and water are known. For example, 10 million wells in Bangladesh and West Bengal are a basic source of drinking water for 95% of the population (Mushtaki 2004). About one million of them provide water with an *arsenic* concentration of 1,000 μg/l, while, according to a World Health Organization (WHO) recommendation, it should not exceed 10 μg/l (Abrahams 2002).

New Zealand, Finland (Tinggi 2003), Oregon (U.S.), Buryatia (Russia), and Estonia are regions with abnormally low concentrations of *selenium* (Microelementoses of humans 1991). Territories with *iodine* deficits exist in all countries except Iceland. The most well known of these regions are the Alps, Andes, Rocky Mountains, Congo River basin, New Zealand, and Papua New Guinea (Fig. 6.2). This problem is most acute in China (Tan et al. 2000).

A deficit of *zinc* is observed in such countries as Egypt, Turkey, Iran, China, Canada, the United States, and Great Britain (Sandstead 1991). Areas with deficits of chromium and excesses of manganese, molybdenum, iron, and other elements are also known (Govorushko 2009).

Anomalous concentrations of one or more microelements result in *diseases* of plants, animals,

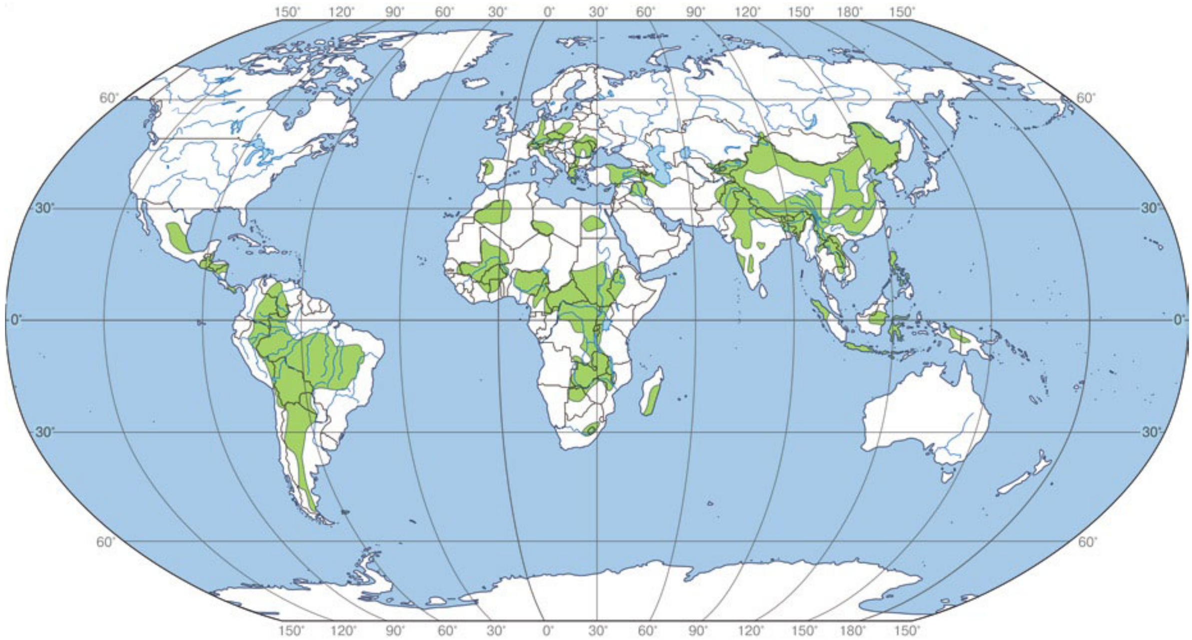

Fig. 6.2 Global distribution of observed iodine deficiency (Dunn and van der Haar (1990). Reproduced with permission of International Council for the Control of Iodine Deficiency Disorders)

and people. Most plants that are grown under unfavourable conditions so far as composition of microelements suffer from endemic diseases causing their loss. The minority of plants adapt and survive. For animals, the opposite situation is observed in similar cases: endemic diseases are characteristic of the minority of animals (Kovalsky 1974).

Microelementoses result in an abrupt reduction in productivity, degradation of products, and other deleterious effects. The most common responses of plants to an unusual geochemical environment are *chloroses* (early ageing of leaves) and *necroses* (death of the plant tissue section). Deficits or excesses of many microelements can cause these disorders.

A large number of *animal diseases* are known. Under natural conditions, a single chemical element that is abundant or scarce in the environment generally can play a decisive role in the contraction of endemic diseases. However, the microelementoses are caused by simultaneously low or increased content in food of several elements (Kovalsky 1974).

In some cases, anomalous concentrations of microelements cause *loss* of animals. An increased content of selenium in soils and vegetation is characteristic of the western states of the United States, quite often resulting in diseases and loss of cattle, horses, pigs, and poultry. It has been stated that the lethal dose of *selenium* for horses is 4.4 mg/kg of weight of an animal (Alekseenko 2005).

The saying "A human is what he eats" is well known. The use by people for food of local products within zones of geochemical anomalies results in deficiencies or excesses of microelements, which can cause different diseases.

A well-known example of such diseases is *goitre*, caused by low contents of iodine in soils and plants. A deficiency of iodine is characteristic of 2 billion of Earth's inhabitants; 655 million people have enlarged thyroid glands (adenoma of the thyroid) as a result of iodine deficiency, and 43 million of them are mentally retarded, including 11.2 million suffering from cretinism (Abrahams 2002).

Bony and dental *fluorosis* related to an increased content of fluorine is also widespread. It is especially characteristic of China, Ghana, Sri Lanka, and other countries. The most problematic situation is in Punjab (India), where fluorosis is characteristic of 83.7% of the people (Microelementoses of humans 1991). In the world, 109 million people are subjected to it (Ji 1999). In *Iceland,* the incidence of fluorosis increases sharply

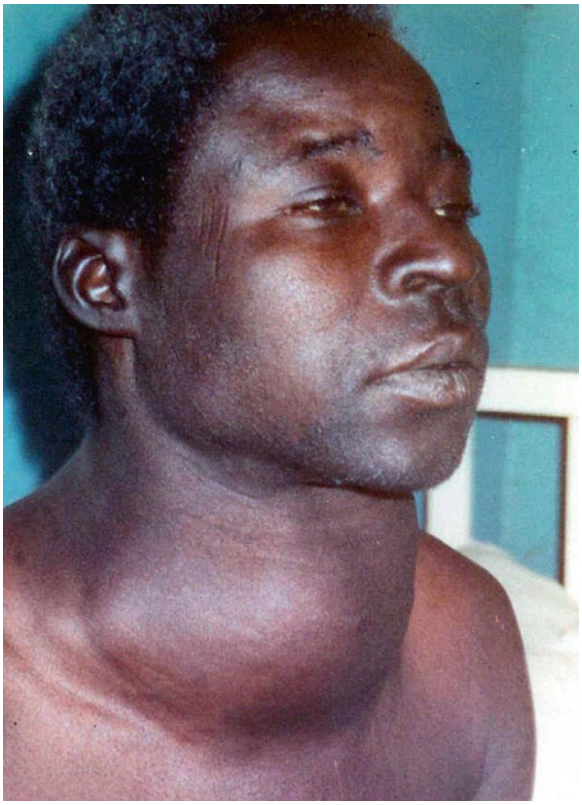

Photo 6.3 Goitres related to lack of iodine are widespread in humans. Hundreds of millions of people in the world suffer from them to a greater or lesser degree. A Nigerian woman with goitre is shown here (Photo credit: Tom D. Thacher, MD)

Photo 6.4 Kashin–Beck disease occurrence is limited primarily to 13 provinces and 2 autonomous regions of China. It also has been reported in Siberia and North Korea. The disease is estimated to affect some two to three million people across China, and 30 million are living in areas where it is endemic. Life expectancy in KBD regions has been reported to be significantly decreased in relation to selenium deficiency. The photo shows a patient diagnosed with Kashin–Beck disease (Photo credit: http://en.wikipedia.org/wiki/Kashin%E2%80%93Beck_disease)

after volcanic eruptions and drops gradually as excess fluorine is leached from the soil and discharged to the ocean with run-off (Perelman and Kasimov 1999).

Many hypotheses have been suggested about the cause of *Kashin–Beck disease*. From one point of view, it is caused by increased contents of *strontium* and *barium* in soils and water against a background of low concentrations of *calcium*. When such water is consumed, the calcium salts in bones are replaced with strontium salts, which are quickly washed out of a human organism. As a result, bones become soft and bend, and peculiar deformities arise (Engineering ecology and ecological management 2003). There are opinions that the cause of Kashin–Beck disease is sulphur deficiency, toxic compounds in food, etc.

According to the most widely accepted point of view, the *main reason* for this disease is a deficiency of selenium. Kashin–Beck disease is, to the maximum extent, prevalent in China, within a belt stretching from the south-west to the north-east. It occurs exclusively among country people who consume vegetable and meat products grown within the endemic regions. The number of people suffering from Kashin–Beck disease in China is, according to different estimates, one to three million people (Selinus and Frank 2000). The number of people in China receiving insufficient selenium is about 400 million. On a *global scale*, their number is estimated at 500 million to 1 billion people (Combs 2001).

Keshan disease is caused by a deficiency of selenium against a background of calcium deficiency. In addition, the introduction of the Coxsackie B virus is necessary

Photo 6.5 Animals also are subject to the effects of microelementoses. Because animals eat mainly local plants – of which an excess or lack of microelements may be characteristic – this has impact on the animals' health. 'Cara inchada' disease – i.e. puffed or enlarged neb (snout) – is characteristic of cattle and is widespread in Brazil. It is related to the imbalance of microelements in soil. Calves affected by cara inchada, epizootic periodontitis of cattle, in the state of Mato Grosso, Brazil, are shown here (Photo credit: J. Dobereiner, Brazilian College of Animal Pathology)

(Ren et al. 2004). It was recorded for the first time in 1907, in the county of Keshan, northern China. Arrhythmia, increases in heart size, and cardionecrosis followed by cardiac insufficiency are characteristic of the disease (Tan et al. 2002).

The influence of microelements on human activities is illustrated by Photos 6.3–6.5.

6.3 Fish Suffocation

Fish suffocation is a phenomenon in which oxygen deficiency in water causes the death of fish and other hydrobionts. Oxygen is necessary for the breathing of fish and other aquatic animals, as well as for natural processes that cleanse water of dissolved organic matter and metabolic products. Oxygen consumption and its production in nature are balanced. However, the oxygen balance can be disturbed for different reasons, which results in the development of fish kill situations.

To the *maximum extent*, fish suffocation is characteristic of (1) stagnant continental reservoirs, especially lakes rich in organic matter where the oxygen concentration is always reduced due to bacterial oxidation and (2) ice-covered water bodies. Fish kills can be of natural, anthropogenic, and mixed origin. Based on the *water body type*, one can identify river, lake, and sea fish suffocations.

Natural river fish suffocations result from the joint action of a number of unfavourable natural *factors*: warm winters and an absence of ice cover to contribute to the clearing and removal of last year's defunct aquatic vegetation from shoaling waters; reductions in water flow rates; comparatively short periods for establishing water levels in the river, contributing to the disappearance of aquatic vegetation; and so on. These factors result in drastically high oxygen consumption for oxidation of plant residues and, as a consequence, in the appearance of fish kill zones (Bukharitsin et al. 2000).

The *stratification* phenomenon is characteristic of water bodies with stagnant water. It is a condition of an aqueous medium in which an abrupt change in hydrochemical conditions is observed at different water depths (horizons). In this case, the water column is divided into two non-intermixing or weakly intermixing water masses.

Under conditions of calm, sunny weather, stratification in shallow water bodies is established every day during the afternoon. At night, the upper layers become cool, and cold water gravitates to the bottom, while the bottom

Photo 6.6 Fish suffocations are a phenomenon in which fish and other hydrobionts die as a result of oxygen deficit in the water. The consequences of herring suffocation in the northern Karaginsky Bay, Bering Sea, are shown. The belt of dead fish was 8 km long, 14–15 m wide, and two to three layers thick. The total quantity of dead fish was 13,000 ton. The death of herring occurred during spawning, and starry flounder, navaga, Atka mackerel, and some other fish species that ate herring eggs also died (Photo credit: A.A. Bonk, Kamchatka Research Institute of Fisheries and Oceanography, Petropavlovsk-Kamchatsky, Russia, May 1998)

layers rise to the surface. *Vertical convection currents* are formed that, toward morning, eliminate the evening stratification phenomenon. The temperature and gas and salt compositions of the water are balanced.

If the water clarity is low, then all the solar energy will be absorbed by the uppermost water layer. It warms up markedly, while the deeper layers remain cold. As a result, it is possible that the highly heated water at the surface *will have no time to cool down* during the night. Its temperature will remain higher than that of the bottom layers, and thus it will be eliminated from the convection mixing process. The oxygen uptake in it will continue, and the reserve of oxygen may be completely exhausted. In cases of prolonged development of this process, the oxygen-depleted zones will spread to the whole water body (Baranova and Yesipova 1982).

Fish suffocations of *anthropogenic* origin occur when excess amounts of nutrients are supplied to a water body, resulting in rapid development of phytoplankton. The intense growth of algae is accompanied by their mass ascent to the upper water horizons. Their accumulation causes a reduction in clarity. A mass dying-off of algae begins, which also results in fish suffocations (Kudersky et al. 1998). Fish suffocations of *mixed* origin occur in cases of joint effects of natural and anthropogenic factors.

One example of *river* fish suffocation is the one that occurred in the Volga delta in the spring of 1999. The abnormally warm winter of 1998–1999 practically eliminated the ice cover within the Volga River delta. Therefore, the previous year's aquatic vegetation, which normally would have been cleaned out in the spring by drifting ice, remained practically undisturbed. Later on, it was immersed. The rotting process beginning in spring intensified in summer in connection with increases in water temperature to 24–26°C. The oxygen dissolved in the water was consumed for oxidation of plant residues. Its content in the water dropped within different sections to 2–6 mg/l (a healthy level of dissolved oxygen is 10 mg/l). This drop resulted in mass fish mortality (Bukharitsin et al. 2000).

Sea fish suffocations are regularly recorded in the north-western shelf of the Black Sea. As a rule, the coastal waters of this sea are not subjected to hypoxia at depths up to 7–8 m, as well as at depths of 30–40 to 150–200 m; below 200 m, in the Black Sea, there is an area permanently contaminated with hydrogen sulphide. The water depleted in oxygen rises in the vertical over the bottom not more than 1–2 m, while above the *thermocline*, life goes on all year round. Therefore, only specialists in the field note oxygen deficits within the bottom layer.

In the event that winds blow from the shore over a long period of time, the waters showing oxygen deficit directly approach a beach, and an extraordinary ecological event comes to light. For example, the north-westerly wind late in July through early in August 2000 drove the warm surface water off to the open sea, and its place was taken by deep, cold water with low oxygen content. At 20 m off the shore at a depth of 1 m, the temperature of the water was 11.2°C, and the oxygen content was 1.8 mg/l. The following figures show the scale of the fish kill: 10–40 dead fish were recorded per one running metre of the coastline from the water's edge to a depth of 1 m (http://www.vokrugsveta.com.ua/S4/bsea2.htm).

The first mass fish suffocation on the Black Sea was observed in August–September 1973, between the Danube River delta and Dniester estuary; it covered an area of about 3,500 km^2. At that time, about 500,000 ton of fish and bottom invertebrate animals were lost. In all, during the period 1973–1990, about *60 million tons of fish* and other hydrobionts were lost in the Black Sea as a result of fish kills.

Similar fish suffocations have been caused by the joint effects of natural and anthropogenic factors. They are also *characteristic* of the northern Adriatic Sea within the zone of influence of the Po River run-off; southern Baltic and North Sea within zones of influence of the Vistula, Niemen, Elbe, and Rhine Rivers; northern Gulf of Mexico within the zone of influence of the Mississippi River; and other regions. Organic pollutants transferred by rivers cause eutrophication of a water body and contribute to fish kills.

The effects of fish suffocation on human activities are illustrated by Photo 6.6.

6.4 Gas Bursts from Basins

Among the numerous lakes on Earth are a number of unique water bodies with high contents of carbon dioxide (CO_2). There are three possible *variants of the carbon dioxide balance* for such lakes: (1) equilibrium, when the amount of supplied gas corresponds to the volumes of its losses; (2) gas bursts, when the replenishment exceeds the losses; and (3) degassing, when losses are more than inflow (Kling et al. 1994).

For the present, *two water bodies* are known from which gas bursts have resulted in human casualties and other negative consequences for human activities. There is also a list of several lakes where similar incidents are possible *in the future*.

The gas burst that happened on 21 August 1986 on Lake *Nyos* is distinguished by the consequences. The lake is located in northern Cameroon (near the boundary with Nigeria). Its area is 1.5 km^2, the volume is about 153 million cubic metres, and the maximum depth is 208 m (Freeth 1992a).

Carbon dioxide first accumulated in the lake hypolimnion (dense lower layers), and later on a sharp burst occurred. Due to its great force, the burst was first considered to be a *volcanic* eruption; however, unbroken layers of bottom sediments and other evidence led to the rejection of this hypothesis (Zhang 1996).

The *limnological* explanation of the gas burst mechanism seems now to be more probable. During rainy season, a layer of cold water forms on the lake surface. Northeasterly wind was predominant in August 1986, causing a surge and thickening of the cold water layer in the southern lake.

If a sufficient amount of surface waters is transferred toward any part of a lake, then eventually they become unstable and sink. Deep, gas-charged waters take their place in the opposite part of the lake. Now, it is impossible to establish the reasons for the water stratification disturbance, but such a scenario is quite probable (Freeth 1992a).

The true *volume* of the gas burst is unknown. The available estimates vary in the range of 30 million (Giggenbach 1990) to 1 billion cubic metres (Andrews et al. 1999). A figure of 100 million cubic metres is considered to be more *probable* (Freeth 1992a). It has been stated that the amount of carbon dioxide remaining in the lake after the catastrophe was about 300 million

Photo 6.7 A limnic eruption is a rare type of natural disaster in which carbon dioxide (CO_2) suddenly erupts from deep lake water. To date, the phenomenon of gas bursts from lakes has been observed only twice. The first was in Cameroon at Lake Monoun in 1984. A second eruption happened at neighbouring Lake Nyos in 1986, this time releasing over 80 million cubic metres of CO_2. The photo shows Lake Nyos, silty after the limnic eruption (Photo credit: Jack Lockwood, U.S. Geological Survey)

Photo 6.8 During limnic eruptions, suffocation of wildlife, livestock, and humans occurs due to asphyxiation. The gas burst at Lake Monoun in 1984 killed 37 people living nearby. The eruption of Lake Nyos was more deadly. It killed between 1,700 and 1,800 people. Losses of domestic animals reached 3,952 cows, 552 goats, 337 sheep, and 3,404 fowl. The photo shows dead cattle and nearby compounds in the village of Nyos (Photo credit: U.S. Geological Survey, 3 September 1986)

Photo 6.9 Lake Kivu is not only 2,000 times larger than Lake Nyos, it is also located in a far more densely populated area, with over two million people living along its shores. Fortunately, it has not yet reached a high level of CO_2 saturation. If the water were to become heavily saturated, it could become an even greater risk to human and animal life. Lake Kivu, Africa, as seen from space is shown here. The black line marks the border between Rwanda and the Democratic Republic of the Congo (Photo credit: National Aeronautics and Space Administration, 2 February 2003)

cubic metres, while its yearly inflow equals 5 million cubic metres (Freeth 1994).

As for the *death toll*, a figure of 1,700 people prevails in the literature (Pourchet et al. 1990; Zhang 1996; and others). Losses of *domestic animals* reached 3,952 cows, 552 goats, 337 sheep, and 3,404 fowl (Freeth 1992a).

A gas burst at Lake *Monoun* happened on 15 August 1984, killing 37 people (Sigurdsson et al. 1987). In spite of the lesser mortality as compared with the event on Lake Nyos, it is believed that Lake Monoun is much more hazardous. It is much smaller, and its depth is two times smaller than that of Lake *Nyos,* but major accumulations of CO_2 are located only 60 m from the surface, and the probability of gas bursts there is higher (Lakes-killers 2003).

Other lakes that are potentially hazardous from the viewpoint of possible gas bursts include Lakes *Bambuluwe*, *Oku,* and *Kivu*. The belief that a hazard exists at Lake Bambuluwe is based on local legends of the periodically blood red colour of its water. Just such a colour was characteristic of Lakes Nyos and Monoun after gas bursts (Pourchet et al. 1990). The belief that a potential hazard exists at Lake Oku is related to loss of life in the past (Freeth 1992b).

The hazard at Lake *Kivu* is related to the fact that, in addition to a huge amount of carbon dioxide (1,000 times greater than in Lakes Nyos and Monoun together) in the lake waters, a considerable quantity of flammable methane is dissolved. This water body is located directly on an active rift, and should cracks open, additional volcanic gases could enter the lake (Lakes-killers 2003).

The effects of bursts of lake gases on human activities are illustrated by Photos 6.7–6.9.

6.5 Underground Fires

Underground fires may be caused by both natural and anthropogenic factors. However, they do not have serious differences in behaviour. Natural underground fires generally arise due to *spontaneous combustion* and rarely due to *magma*, *lightning strikes,* or *forest fires* (http://www.gi.alaska.edu/~pracash/coalfires/causes_hazards.html).

In most cases, underground fires are related to *fossil fuels* (coal, Dictyonema oil shale, and peat). Sometimes, the fires arise in *ore deposits*. Copper–nickel ores of sulphide deposits are characterised by a tendency to combust spontaneously (Valukonis and Prikhodko 2002).

Some of the *factors affecting the spontaneous combustion* of coal are (1) geology of the coal bed (the greater the angle of incidence of a bed, the more probable the spontaneous ignition)(based on this factor, coal beds are subdivided into low hazard – angle of incidence is less than 25°, moderately hazardous – angles of 25–50°, and hazardous – more than 50°); (2) depth of its occurrence (the deeper the bed, the smaller its inclination to spontaneous combustion); (3) bed thickness (the probability of spontaneous combustion increases with increasing thickness); (4) gas content of

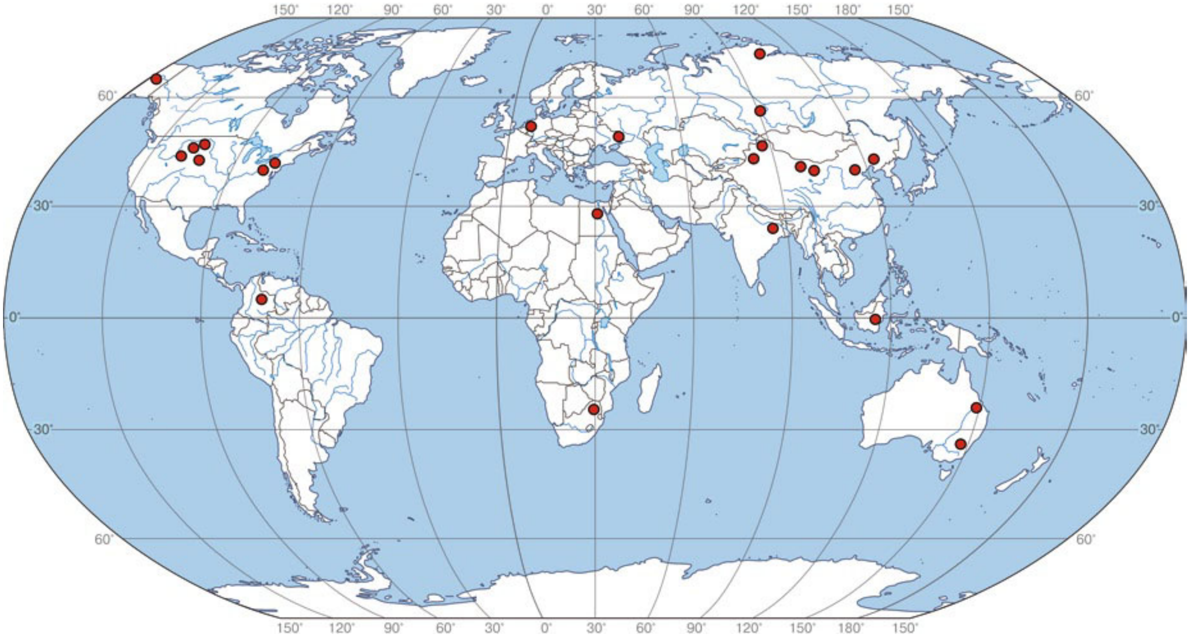

Fig. 6.3 Global distribution of coal fires (Reproduced with permission of Prof. A. Prakash, University of Alaska, Fairbanks)

the coal (the higher the gas content, the lesser the probability); and (5) its chemical activity (determined by oxygen absorption rate, humidity, and presence of admixtures) (Valukonis and Prikhodko 2002; Stracher and Taylor 2004; http://www.gi.alaska.edu/~pracash/coalfires/coalfires.html).

Coal reacts with atmospheric oxygen even at ambient temperatures, and this reaction is exothermic. If the heat liberated during the process is allowed to accumulate, the rate of the reaction increases exponentially and there is a further rise in temperature. When the temperature reaches the *ignition temperature* of coal, the coal starts to burn; this phenomenon is described as *spontaneous combustion* (http://www.itc.nl/personal.coalfire/problem/factors.html). The global distribution of coal fires is shown in Fig. 6.3.

The *temperatures* at which the coal oxidation reaction becomes sustaining and at which spontaneous combustion occurs vary, generally depending on the type (nature and rank) of the coal and the surrounding conditions of heat dissipation. In poor-quality coal where the heat retention is high, the coal and carbonaceous material may start burning at temperatures as low as 30–40°C. So *three factors* – fuel, oxygen, and heat – are necessary (http://www.gi.alaska.edu/~pracash/coalfires/spontaneous_combustion.html).

An *example* of an event when underground fires arose for reasons other than spontaneous combustion is the underground combustion of coal in Indonesia. When forest fires were raging under conditions of severe drought in 1997, about 700 underground fires arose in the coal beds of eastern Kalimantan Island (Revkin 2002).

A concrete example of natural underground fires is the combustion of bituminous shale on the east coast of Cape Bathurst (Canadian coast of the Beaufort Sea). This locality (*Smoking Hills*) was discovered in the 1920s, and the fire has lasted up to now (Forces of nature 1998).

An underground fire in the village of Agrafenovka, near Saratov, Russia, is also widely known. The fire arose in February 1909. A landslide in 1908 triggered

Photo 6.10 The Smoking Hills are located on the east coast of Cape Bathurst in Canada's Northwest Territories. The cliffs were named by explorer John Franklin, who discovered them during an expedition in 1826. They contain strata of hydrocarbons (oil shale), which have been burning for centuries without cessation. The fires result from autoignition of sulphur-rich lignite deposits (Photo credit: Ansgar Walk, 2 September 2010)

spontaneous combustion. As a consequence of the landslide, air began to freely enter the underlying rocks. The exothermal reaction between oxygen and pyrite started, resulting in the combustion of black clay shale (Larionov 1974).

On the shore of the Gulf of Finland (Estonia), Dictyonema oil shales burned for a long period. In Tajikistan (nick Kukhi-Malik in the Yagnob River valley), the prolonged combustion of coal beds was recorded (Valukonis and Prikhodko 2002).

Once they arise, underground coal fires may exist for a *long time*. For example, Australia's Burning Mountain, the *oldest known coal fire*, has burned for 6,000 years (http://www.wikipedia.org/wiki/Mine_fire).

Near-surface peat deposits often ignite spontaneously in summers of dry years. The ignitability of peat *depends on* its botanical composition, degree of decomposition, and physico-chemical properties (Valukonis and Prikhodko 2002).

Catalytic combustion of peat layers 0.3–1.5 m thick is generally characteristic of peat fires. Peat can ignite spontaneously and burn in the absence of air and even under water. Over the fire peatlands, 'columnar eddies' of embers and ignited peat dusts can form, which can be transferred by strong winds for large distances and cause new fires or burns of people or animals.

The distinguishing *features* of peat-bog fires are relatively small areas, high stability of combustion, and huge amounts of fumes. The *velocity* of their propagation is tens and hundreds of metres per day.

The effects of underground fires on the *health of people* are related to changes in atmospheric composition. Countries such as China, India, and Indonesia suffer from them to the greatest extent. For example,

Photo 6.11 Near-surface peat deposits often ignite spontaneously in summers of dry years. The ignitability of peat depends on its botanical composition, degree of decomposition, and physico-chemical properties. Mass peat fires started in the Moscow region in July 2002. Some of them remained 9 months later (Photo credit: V. Kantor, Greenpeace Russia, March 2003)

Photo 6.12 Countries such as China, India, and Indonesia suffer from underground fires to the greatest extent. Large numbers of underground coal-mine fires are also characteristic of the state of Pennsylvania (U.S.). The photo shows a sign warning of a local underground fire (Photo credit: http://en.wikipedia.org/wiki/Centralia,_Pennsylvania)

120 million tons of coal burn with the release of 360 million tons of CO_2 every year in China (Scott 2002). For fairness' sake, it should be noted that all underground fires (both natural and anthropogenic) are taken into account. In Moscow, in July 2010, about 200 people met untimely deaths every day during peat fires as a result of air pollution by combustion products (Yablokov 2010).

The influence of underground fires on human activities is related first of all to visibility deterioration. It is predominately expressed as the complication of the functioning of different modes of *transport*.

For example, the *visibility* in the Moscow area in 2002 decreased at times to 50–100 m during peat-bog fires, which created problems for the operation of *motor* and *rail* transport. *Air travel* also suffered from

Photo 6.13 During peat-bog fires in 2002, the visibility in the Moscow area decreased at times to 50–100 m, creating problems for the operation of motor and rail transport. Air travel also suffered from these fires. Numerous flight delays occurred, and airplanes were directed to alternate airports. The photo shows smoke in Dubna (town near Moscow) (Photo credit: D. Volgin, GeoPhoto, Russia)

these fires. Numerous flight delays occurred, and airplanes were directed to alternate airports. Even emergency landings were recorded (Grigoryev 2003).

The effects of underground fires on human activities are illustrated by Photos 6.10–6.13.

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Cosmic Processes 7

Abstract

Cosmic processes are processes that result from the movement of cosmic bodies with respect to each other or changes that take place within a cosmic body. Among the vast variety of cosmic bodies, the Sun and Moon (in addition to Earth) are most important to humanity. Alternation of day and night is caused by the Earth's rotation about its axis; monthly and weekly rhythms result from the Moon's circuit of the Earth. The changes of the seasons are related to the Earth's circuit of the Sun (and the inclination of the Earth's axis), while alternation of good and bad years is related to solar activity. It is responsible for three more kinds of rhythm: 11-, 22- to 23-, and 80- to 90-year periods. Because, in addition, there are gravitational couplings between planets, movement of comets, and many other interactions, the number of cosmic rhythms may be considerable. It is plain that all of them, one way or another, have effects on nature (both animate and inanimate) and humans. In principle, the whole lifetime of nature and humans is determined, to a greater or lesser degree, by cosmic processes. In this chapter, those processes that have the greatest influence on human activities are considered.

Keywords

Sun • Moon • Earth • Human activities • Asteroids • Meteors • Origin • Economic loss • Mortality

7.1 Collisions with Cosmic Bodies

Our planet continually meets with small cosmic bodies. The smallest of them burn down completely in the dense atmosphere. Such bodies are called *meteors* among scientists or *'shooting stars'* among laypeople. The larger bodies burn down in the atmosphere only in part and fall to the ground. In flight, such bodies are called *bolides,* and when they reach the Earth's surface, they are called *meteorites*. Collisions of the Earth with *asteroids* (celestial bodies of 1–1,000 km in diameter) and *comets* (icy celestial bodies of 0.5–20 km in diameter) are possible.

The collision *speed* depends on the correlation of the direction of the Earth's movement and the fall of the cosmic body. It always exceeds the *second cosmic speed* (11.2 m/s). The maximum possible speed of a collision is 70 m/s (Threat from the sky 1999).

When a meteorite falls to the Earth's surface, it forms a *crater*, or an *impact structure*. This process consists of the following *stages*: (1) contact and compression (in this case, the meteorite penetrates 1–2 diameters into the ground); (2) propagation and attenuation of shock waves; and (3) crater excavation. The second and third stages overlap in time (Vishnevsky 2007). The *ages* of

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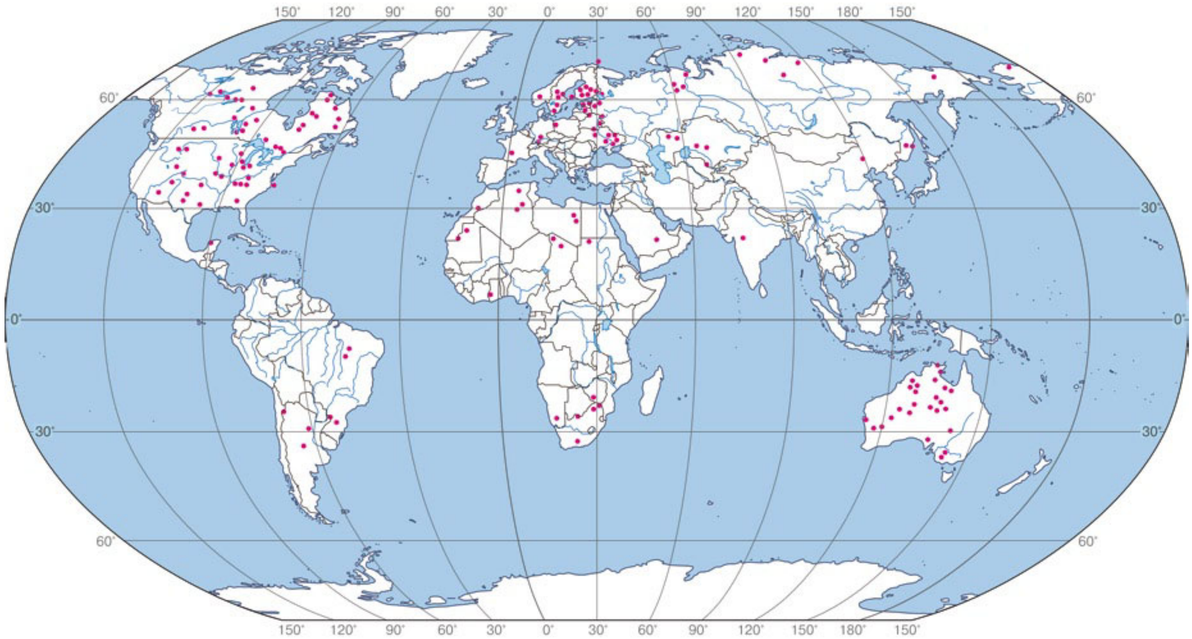

Fig. 7.1 Known craters formed due to impacts of cosmic bodies (Compiled by author with the use of the Earth Impact Database of the Planetary and Space Science Centre of University of New Brunswick, Canada; http://www.passc.net/EarthImpactDatabase/index.html)

most ancient earthly craters reach two billion years, and their sizes vary from several tens of metres to several tens of kilometres (Gurov 2004).

The *distribution* of known craters on the Earth's surface is uneven, but this is not to say that there are some peculiarities in their impacts. Their different concentrations are determined by how extensively a region has been explored and how well a crater has held its shape. At the beginning of 2007, 176 impact structures of various ages were known on the Earth (Vishnevsky 2007). However, this figure is not final. Every year, four to five new craters are found on the Earth (Gurov 2004). Known craters formed due to impacts of cosmic bodies are shown in Fig. 7.1.

The most well-*known* and thoroughly studied crater on Earth is located in Arizona (United States). Meteor Crater was formed 50,000 years ago as a result of the impact of a nickel–iron meteorite with a speed of 20 m/s. Its weight was several hundred thousand tons, and the diameter was 46 m. The impact energy corresponds to 20 million tons of TNT and, as a result, a crater with a diameter of 1,219 m and a depth of 213 m was formed (http://www.meteorcrater.com/Mcrater.htm).

There are several theories about the *origin* of meteorites. In accordance with the most widely accepted of them, meteorites generally form from asteroids within the belt between Mars and Jupiter. At the same time, it has been proved that some of them originate from the surface of Mars, while others originate from the surface of the Moon (Koronovsky 2010).

The *asteroids* dangerous for the Earth are those with orbits that penetrate the orbit of the Earth (Threat from the sky 1999). *Comets* also fall to our planet. Though the comet stream is only a few percent of the asteroid stream, the *speed* of their fall (from 30 to 60 m/s) noticeably exceeds the typical speed of an asteroid's fall (20 m/s). Therefore, their kinetic energy is several times larger than that of similar-sized asteroids, and they account for approximately 25% of the impact hazard to the Earth (Chapman and Morrison 1994).

Based on the *material* composition, meteorites are subdivided into three *classes*: (1) stony (aerolites) (91.5% of falls); (2) iron (aerosiderites) (6.6%); and (3) stony–iron (1.9%) (Hughes 1980). On impact, meteorites explode into great numbers of *fragments*. Their number depends on many factors. Analysis of

Photo 7.1 Meteor crater, the most well-known and thoroughly studied crater on earth, is located in Arizona (United States). It was formed 50,000 years ago as a result of the impact of a nickel–iron meteorite with a speed of 20 m/s. Its weight was several hundred thousand tons, and the diameter was 46 m. The impact energy corresponded to that of 20 million tons of TNT and, as a result, a crater with a diameter of 1,219 m and a depth of 213 m was formed. The photo is an aerial view of the Winslow, Arizona, Meteor Crater, looking from the south-south-west (Photo credit: Robert J. Boser, http://www.airlinesafety.com/editorials/AboutTheEditor.htm, January 1966)

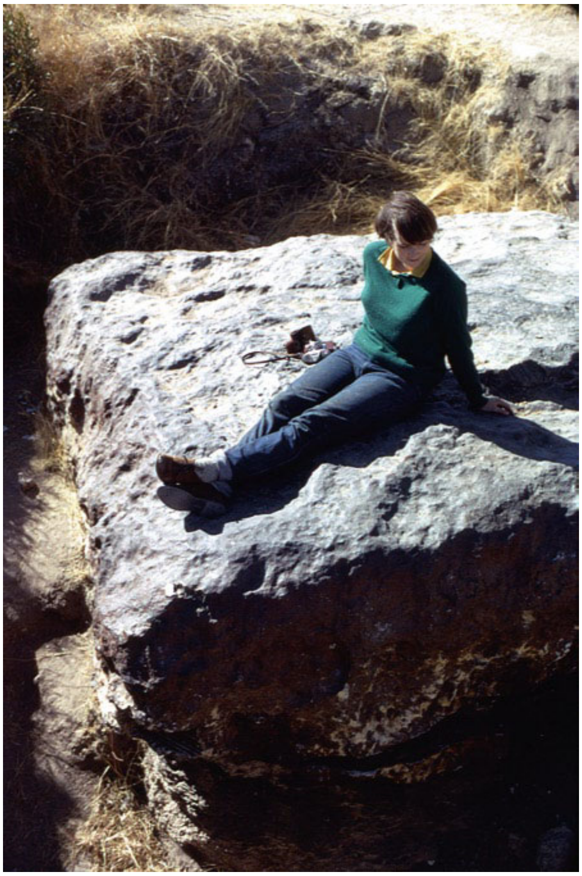

Photo 7.2 Hoba is a meteorite that lies on the farm 'Hoba West', not far from Grootfontein, in the Otjozondjupa Region of Namibia. It has been uncovered, but because of its large mass, it has never been moved from where it fell. The main mass is estimated at over 60 ton, and it is the largest known meteorite (existing as a single piece) and the most massive naturally occurring piece of iron known at the Earth's surface (Photo credit: Paul Venter, 26 July 1967)

470 impacts of meteorites that occurred during the period 1800–1925 showed that the average number was 277.2 fragments per impact (Hughes 1992).

Every year, about 19,000 meteorites with masses of more than 100 g fall on the Earth; 4,100 of them have masses of more than 1 kg, and 830 have masses greater than 10 kg. Their *total mass* is about 21.3 ton. On one million square kilometres of land, approximately 40 meteorites with masses of more than 100 g fall, on average, each year (Kurbatova et al. 1997). The probabilities of impacts by *larger* celestial bodies are estimated as follows: a 60-m (in diameter) body once every 3,000 years; a 100-m body once every 5,000 years; a 1-km body once every 300,000 years; and a 10-kilometre body once every 100 million years (Vorobyev et al. 1997).

In discussing the effects of collisions of cosmic bodies with the Earth on *human activities*, it should be remembered that there is no upper limit on their destructiveness and the extinction of all life is possible. In cases of less severe global consequences, the scales of mortality and the kinds of activities affected depend strongly on the point of impact. The number of known cases of loss of life due to impact is very small. In addition, the reliability of the available information varies.

The most complete list of impacts of meteorites that resulted in *loss of life* is given in a monograph by J.S. Lewis (1996). According to his investigations, meteorite impacts over the period of written history have caused thousands of deaths. He has analyzed 123 recorded cases in which people have been killed or wounded. A list given in the book *Threat from the Sky: Fate or Fortuity* (1999) numbers 18 incidents causing loss of life over the period AD 588 through 1992 and 11 cases when the impacts of meteorites injured people. Information on loss of life is also presented in other publications (Halliday et al. 1985; Mezentsev 1988; Yau et al. 1994).

In the overwhelming majority of incidents, only a *single person* has suffered. In an account of one case that stands apart, 10,000 people were killed in February 1490, in the territory of the present-day province of Shanxi, China (Threat from the sky 1999); however, the believability of this information is doubtful. At least, in a detailed paper by K. Yau et al. (1994) devoted to impacts of meteorites in China, this case is not mentioned. Generally, one can assert that the loss of life caused by meteorites, up to now, has been an exceptionally rare event.

As for the effects on engineering structures, no activity can be excluded from consideration. In this case, it is worthwhile to consider recorded events. They include *effects on* (1) industrial and civil engineering; (2) motor transport; (3) water transport; (4) telephone communications; and (5) space activities (Govorushko 2009).

There is much evidence concerning effects on *industrial* and *civil engineering*. Over the period 1965–1984, seven such cases were recorded in the United States and Canada; nine buildings sustained considerable damage (Halliday et al 1985). In one work (Threat from the sky 1999), it is asserted that throughout the past 500 years, 27 cases of meteorite impacts on buildings have been recorded. Damage caused by a meteorite to the dome of a church in Tobolsk (Russia) in 1684 is described in one monograph (Mazur and Ivanov 2004).

A detailed description was devoted to the destruction in AD 616 of a fortress tower in China. In spite of the remoteness of this event, information is considered to be very reliable because it belongs to a formal description of the Sui Dynasty (Yau et al. 1994). An exceptional example is one of buildings in Wethersfield, Connecticut (United States), on which meteorites fell *twice* (in 1971 and 1982) (Forces of nature 1998).

Some influence on *motor transport* has also been recorded. A case that occurred on 9 October 1992 is well known, when a meteorite weighing12.3 kg broke through a car trunk (Threat from the sky 1999). Chapman and Morrison (1994) also tell of several cases of impacts of meteorites on cars.

There is evidence that meteorites have fallen on *sea vessels*. A meteorite fell in 1648 on the ship *Malacca*, which was proceeding from Holland to Batavia (now Jakarta) (Yau et al. 1994). A small meteorite fell on 29 January 1957 on the Soviet steamship *Izmail*, which was proceeding from Calcutta to Odessa (Mezentsev 1988).

The interruption of *telephone communication* on 30 November 1946 in the city of Colford, United Kingdom, is described in the book *Threat from the Sky: Fate or Fortuity* (1999). Damage to the body of the International Space Station by a micrometeorite was found on 6 June 2007 by crewmen during a spacewalk (http://www.rambler.ru/news/science/spacenews/10518577.html).

The effects of meteorites on human activities are illustrated by Photos 7.1–7.4.

Photo 7.3 There have been several cases of meteorites striking cars. The photo shows the Benld meteorite (inset) and the car seat and muffler hit by the meteorite in 1938 (Photo credit: http://en.wikipedia.org/wiki/Meteorite)

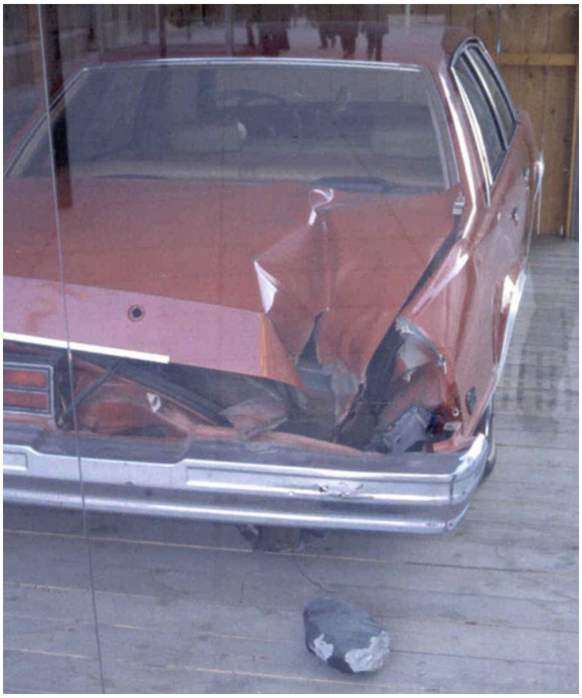

Photo 7.4 The most recent case of a meteorite influencing motor transport is the Peekskill meteorite. The photo shows the effects of the impact of a 12.3 kg meteorite into the back of a parked Chevrolet Malibu car. It happened on the evening of 9 October 1992 in Peekskill, New York (Photo credit: National Aeronautics and Space Administration)

7.2 Magnetic Storms

Magnetic storms are strong disturbances of the Earth's magnetic field that abruptly violate the smooth diurnal variations of terrestrial magnetism elements. The *duration* of magnetic storms is several hours to several days, and they are observed simultaneously throughout the Earth. The maximum *intensity* of magnetic storms is characteristic of the high latitudes.

The temperature of the Sun's upper atmosphere (corona) is about a million degrees. Plasma streams migrate permanently from the corona to the space environment. These streams are the *solar wind*, which travels at about 300 km/s. Spots of strongly magnetized material periodically come to the surface of the Sun from the Sun's interior (the magnetic fields of the spots are thousands of times stronger than Earth's magnetic field). When spots with different magnetic polarities approach each other, a giant 'short circuit' takes place with the release of a tremendous amount of energy. This phenomenon is called a *solar flare* (http://www.magnitventil.ru/index.php?option=com_content&task=view&id=33&Itemid=42).

During the 11-year cycle of solar activity, about 37,000 flares are recorded on the Sun (Mazur and Ivanov 2004). However, our Earth is a very small target in relation to the Sun, and most of the plasma goes past the Earth. In the case that it reaches the Earth's magnetosphere, a shock wave forms. At the contact point, strong *variations of the intensity* of terrestrial magnetism are observed. Because the speed of the disturbed solar wind is 500–1,000 km/s, the magnetic storm begins 1–2 days after the flare.

According to their *intensity*, magnetic storms are subdivided into five *categories*. The strongest ones fall into the fifth category, and they are observed four times during an 11-year period and last a day, on average. The weakest storms happen 1,700 times and last cumulatively 900 days (Pirjola 2000).

In the course of magnetic storms, *geomagnetically induced currents* arise on the surfaces of metal structures.

Magnetic storms influence human health. They also affect the following *kinds of human activity*: (1) energetic objects; (2) transmission lines; (3) different modes of communication; (4) pipelines; (5) rail transport; (6) space activities; and (7) the search for mineral deposits.

The influence on human *health* is expressed as a general loss of condition and increased probability of initiation of problems with the cardiovascular system. During strong magnetic storms, the number of *cardiac infarctions* increases by 13% while that of cerebral strokes increases by 7.5% (Fedyunina 2004). During periods of heliomagnetic activity, the numbers of *errors* in work by control room operators, locomotive engineers, and motor transport drivers increase For example, driver reaction times quadruple, while the numbers of road accidents double during magnetic storms (Kurbatova et al. 1997).

Geomagnetic disturbances can have serious effects on *power systems*. A current induced in transmission lines is earthed through substation transformers. Below the ground, the current results in transformer core saturation. The increased heating can cause transformers to burn out. In addition, relays are often actuated and abruptly shut off current transfer. The shutdown of compensators is also possible (http://www.spaceweather.gc.ca/power_e.shtml).

The events that occurred during the failure in the Hydro-Quebec Power System on 13 March 1989 developed in just such a sequence. The geomagnetically induced currents resulted in the collapse of the entire network 1.5 min after the beginning of the magnetic storm, resulting in the loss of 21,500 MW of load. Nine hours after the failure, 17% of the power system load had not been put into place (Pirjola 2001a). *Economic losses* caused by this failure reached US$13.2 million (http://www.spaceweather.gc.ca/power_shtml).

The same magnetic storm also disabled the transformer in the Salem Nuclear Power Plant (New Jersey, United States) due to overheating; the transformer had to be replaced. *Economic losses* amounted to several million dollars (Jansen et al. 2000).

Photo 7.5 The magnetic storm on 13 March 1989 disabled the transformer in the Salem Nuclear Power Plant (New Jersey, United States) due to overheating; the transformer had to be replaced. Economic losses amounted to several million dollars. The photo shows the damaged transformer (Photo credit: John Kappenman, Public Service Electric and Gas of New Jersey)

The effects on *transmission lines* are also related to the fact that magnetic disturbances induce electric current in the long conductors. Often, they are damaged. In transmission lines that run on alternating current with frequencies of 50–60 Hz, the induced currents are insignificant (Mazur and Ivanov 2004). Impacts on direct current transmission lines are greater.

Different *communication* modes are subject to the effects of magnetic storms to a considerable extent. Low-voltage communication lines show greater damage. For example, when a fuse blew as a result of geomagnetically induced currents, *telephone lines* in Finland went out of service in February 1958 (Pirjola 2001b). In the Midwest of the United States, a *cable telephone line* was shut down on 4 August 1972. In 1847, all telegraph lines in Great Britain shut down as a result of a magnetic storm (Boteler et al. 1998). In 1921 and 1958, geomagnetically induced currents resulted in *fires* in telegraph exchanges in Sweden (Jansen et al. 2000).

Solar flares also create serious interference to *radio communications*. In the course of magnetic storms, high-frequency radio communication in the polar areas often becomes impossible, and the duration of such periods may reach several weeks (http://www.spaceweather.gc.ca/hfradio_e.shtml). Magnetic storms also create problems for the operation of *submarine cables*. For example,

Photo 7.6 This photo shows internal damage that occurred in this transformer (see Photo 7.5) due to geomagnetic induced current (GIC). The presence of GIC causes saturation of the core steel of a transformer and creates stray flux that can be so intense that it creates hot spots in regions of high flux concentrations (Photo credit: John Kappenman, Public Service Electric and Gas of New Jersey)

in February 1958, transatlantic communication from Clarenville, Newfoundland, to Oban, Scotland, consisted of loud, shrilly sounds alternating with low whispers when the naturally induced voltage was activated with the voltage of the cable power supply or against it (http://www.spaceweather.gc.ca/cable_e.shtml).

The effect of magnetic storms on *pipelines* is expressed as the creation of geomagnetically induced currents. These currents intensify electrochemical corrosion at points of insulation failure. In order to provide protection, special devices – cathodic protective rectifiers – are fastened to pipes (http://www.spaceweather.gc.ca/pipeline_e.shtml).Geomagnetically induced currents are sometimes the cause of fires and explosions in oil and gas pipelines (http://www.magnitventil.ru/index.php?option=com_content&task=view&id=33&Itemid=42). In addition, flow meters in pipelines can transmit false information on volumes of oil or gas transport.

The influence on *rail transport* has been expressed as inactivation of the traffic control system. For example, a catastrophe in which 19 people were killed happened in January 2000. As the experts have stated, the semaphore signal 'the way is clear' led to this railway accident. The equipment error was caused by a magnetic storm (Jansen et al. 2000).

The effects of magnetic storms on *space activities* are significant. The plasma streams emitted by the Sun in the course of flares give *satellites* an additional and irregularly distributed negative electric charge. The potential difference between the neighbouring components of a satellite can reach several tens of kilovolts. This provokes spontaneous electric discharges that can disable the electrical equipment on the satellite (Mazur and Ivanov 2004). The faulty operation of stabilization gyroscopes is often recorded, which can cause a satellite to leave its orbit and burn up in the dense atmosphere (http://www.magnitventil.ru/index.php?option=com_content&task=view&id=33&Itemid=42).

Two well-known examples are the breakdown of a Canadian *Anik* communications satellite on 20–21 January 1994 and the American communication satellite *Telstar 401* on 11 January 1997. As a result of the second accident, much of the United States was left without *paging communication* (Jansen et al. 2000).

In the course of powerful flares, the flux of ultraviolet radiation increases by factors of 10, which, together with the matter ejected by the flare, results in heating of the upper Earth atmosphere. In this case, the atmosphere expands and begins to brake the movement of satellites, which can cause their unplanned premature *exit from orbit*.

One more aspect of the influence of solar flares on space activities is complication of the operation of the Global Positioning System. A GPS receiver uses radio signals from several orbiting satellites, determines the distance of a point on the Earth from every satellite, and reveals the actual position. Plasma ejections during magnetic storms change the speed of radio-wave propagation, and the amount of change is not constant. This causes errors in range determination and, consequently, in determination of the location of the user (http://www.spaceweather.gc.ca/effectsgps_e.shtml; Skone 2001).

The effect on the *search for mineral deposits* is generally expressed as complication of high-resolution magnetic surveys. In most cases, a survey is put off until the magnetic storm is over. In addition, the storms affect exploratory drilling. For example, during a magnetic storm on 13 March 1989, companies investigating the bottom of the North Sea experienced problems in the operation of logging devices that controlled drilling heads (Randell 2002).

The annual *economic losses* from magnetic storms amount to hundreds of millions of dollars (Slater and Linford 2004).

The effects of magnetic storms on human activities are illustrated by Photos 7.5 and 7.6.

7.3 Regime of Solar Illumination

It is known that the duration of *daylight hours* in winter is less than that in summer. The higher the latitude, the greater are these differences. The deficiency of natural light is a cause of *Seasonal Affective Disorder (SAD)*, a state in which repetitive psycholepsies are characteristic. They arise in autumn or in winter and remit in spring and in summer. Information on the disease appeared before 1845 (http://www.nmha.org/infoctr/factsheets/27.cfm), but it was first described only in 1984 (Mersch et al. 1999a).

Afflicted persons show typical *symptoms* of depression: low spirits, dying to the world, difficulty concentrating, decreased activity, and undue fatigability. *Other symptoms* are hypersomnia (70–80% of patients), limosis, marked weight gain (70–80%), and increased demand for carbohydrates (80–90%) (http://www.nmha.org/infoctr/factsheets/27.cfm).

The disease is closely related to increases in the duration of the *winter night* and, therefore, to higher *latitudes*. For example, the incidence of Seasonal Affective Disorder in the state of Washington (United States) is seven times higher than that in Florida (http:www.findarticles.com/cf_0/m3225/5_61/61432742/p1/article.jhtml). The disease is recorded in both the northern and southern hemispheres (Haggarty et al. 2002).

Practically all investigations on the subject have noted that *females* are more susceptible than males are to this disease. Some sources (http://www.nmha.org/infoctr/factsheets/27.cfm; Saarijärvi et al. 1999; http://info.med.yale.edu/psych/clinics/winterdep.html) state that females are ill with SAD four times more often than males; however, the average ratio for all investigations is approximately 1.8:1 (http:www.psychdirect.com/depression/d-treatmentguidelinesSAD.htm).

The incidence of the disease increases with *age* to 50 years; after that, its spread decreases sharply, and after 60 years, this disease is infrequent (Haggarty et al. 2002). It is believed that native persons of the northern territories have developed tolerance to winter darkness through *genetic selection*. A comparison of morbidity for different groups of populations (emigrants from Iceland and other countries in Canada, Laplanders and Finns residing in Lapland, and so on) reveals lower indices for ethnic groups who have lived under Arctic conditions for a long time. It is believed that the contribution of the genetic factor to tolerance of winter darkness is about 30% (Saarijärvi et al. 1999).

As to the *cause* of Seasonal Affective Disorder, melatonin, a sleep-related hormone secreted by the pineal gland in the brain, has been considered. This hormone forms with increases in the amount of time spent in the dark (http://www.nmha.org/infoctr/factsheets/27.cfm).

The *share* of the *population* that suffers from Seasonal Affective Disorder for some *countries* is as follows: 1.4% in the United States (Blazer et al. 1998), 1–2% in Japan (Lam 1998), 2–3% in Canada (Canadian consensus guidelines for the treatment of seasonal affective disorder 1999), 2.2% in Switzerland, 3.8% in Iceland, 3.9% in Sweden, and 7.1% in Finland (Mersch et al. 1999b). A few estimates for some *regions* and settlements are as follows: 1–3% in Ontario (Canada) (http://www.psychiatry.ubc.ca/mood/sad/pcp_sad.htm), 9.2% in Alaska (United States) (http://www.mentalhealh.com/book/p40-sad.html), and 6.3% in an Inuit settlement (Canadian Arctic region) (Haggarty et al. 2002).

There is also a *milder form* of this disease with similar symptoms (so-called *Subsyndromic Affective Disorder*, or 'winter blues'). The number of people suffering from the mild form of the disorder is three times higher than the number suffering from the more severe form (http://www.sltbr.org/sadfag.htm).

The effects of Seasonal Affective Disorder on human activities are illustrated by Photo 7.7.

Photo 7.7 A deficiency of natural light is a cause of Seasonal Affective Disorder (SAD). Bright light therapy is a common treatment for SAD and for circadian rhythm disorders. A 30 kHz bright light therapy lamp (Innosol Rondo) used to treat seasonal affective disorder is shown here. It provides 10,000 lx at a distance of 25 cm (Photo credit: http://en.wikipedia.org/wiki/Light_therapy)

7.4 Cosmic Radiation

The natural background radiation of the Earth is of both terrestrial and cosmic origin. The share of radiation incident to the Earth's surface *that originates from space* is slightly less than 50% (Vakhromeev 1995). Cosmic rays are subatomic particles moving with the speed of light. About 87% of cosmic rays are protons (hydrogen nuclei), 12% are alpha particles (helium nuclei), and about 1% consists of small amounts of all other elements. Generally, they are deflected by the terrestrial magnetic field, but the more energetic particles may penetrate the Earth's atmosphere (http://www.jpnet.me.uk/school/radiation/source1.htm). Constant vertical cut-off rigidity of neutrons is shown in Fig. 7.2.

Cosmic radiation is subdivided into two *types*: primary and secondary. The major part of the *primary* radiation comes from beyond the solar system. Its specific origin is unknown, but it is thought that this primary radiation may be product of *supernovae*, from which a huge amount of radioactive energy is released, and even products of the '*Big Bang*' (http://www.jpnet.me.uk/school/radiation/source1.htm).

The remaining part comes from the Sun; this radiation is formed in the course of *solar flares*. Such flares occur quite infrequently. Over one solar cycle (11 years), on the order of three flares, can be expected (http://www.sec.noaa.gov/info/RadHaz.html). An extremely insignificant part of the released radiation reaches the Earth. The radiation beam is deflected by the geomagnetic field and thus is not restricted to the sunlit hemisphere (http://resources.yesican.yorku.ca/trek/radiation/final/index_natural_par.html).

Secondary cosmic rays are products of interactions between cosmic radiation and the atmosphere. During these interactions, much of the energy of the protons and alpha particles is lost, and near the earth surface, cosmic radiation is largely represented by photons, beta particles, and neutrons. Its intensity depends on altitude, latitude, and solar activity (Durikov 1993).

The dependence on *altitude* is evident. The atmosphere protects against space radiation; therefore, the secondary particle intensity increases with altitude. For example, in the north-eastern United States, a typical space radiation dose on the surface is 4 microröntgens per hour; at an altitude of 4,570 m, it is 5 times higher, while at an altitude of 16,760 m, its value is 75 times higher than that on the surface.

The relation with geographic *latitude* is also easily explained. The magnetic field weakens the space radiation. At sea level, the intensity of cosmic radiation drops by about 10% in moving from the poles to the equator. As for *solar activity*, its maximum intensity is observed in the course of flares (http://www.physics.isu.edu/radinf/natural.htm).

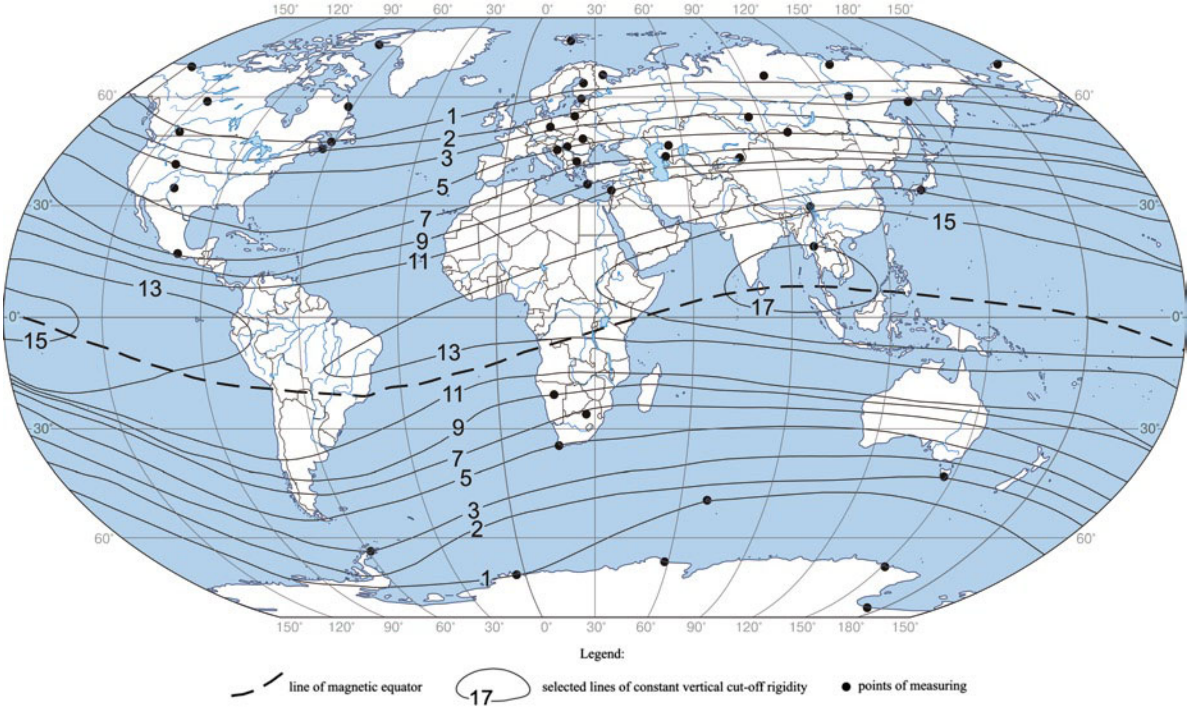

Fig. 7.2 Cosmic ray neutron monitors, 2010 (Reproduced with permission of Dr. Roger Pyle). The "1" contour is the highest count rate and "17" the lowest. The neutrons are just the neutron component of the high-altitude proton (and some alphas) air showers as seen at the Earth's surface. The cutoff rigidity of a station, in simplest terms, is the rigidity below which the cosmic rays are excluded by the geomagnetic field

Cosmic radiation affects the *kinds of human activity* that occur at considerable heights: (1) space activities; and (2) air transport. In the course of solar flares, cosmic radiation can constitute a serious danger for *cosmonauts and astronauts*. During operations in Earth orbit, a spacecraft may be quickly returned to the Earth. However, in the case of interplanetary missions, astronauts would need to be provided with adequate shielding in their spacecraft (http://resources.yesican.yorku.ca/trek/radiation/final/index_natural_par.html). In cases of extravehicular activity during interplanetary flights, cosmonauts may receive lethal radiation doses.

The influence of cosmic radiation is also significant for *aircrews*. A 2-h flight at traditional altitudes may double the dose of ionizing radiation received by a person per day, which does not seem to be dangerously high (http://www.sec.noaa.gov/info/RadHaz.html). Long, regular flights, however, may increase a dose to dangerous limits. Examination of the health of 28,000 pilots and flight engineers of nine European countries revealed an increased incidence of *malignant melanoma* (Bletner et al. 2003).

Photo 7.8 The influence of cosmic radiation is significant for aircrews. A 2-h flight at traditional altitudes may double the dose of ionizing radiation received by a person per day, which does not seem to be dangerously high. Long, regular flights, however, may increase a dose to dangerous limits. The photo shows measurements of a peak dose rate during a 1-h flight at an altitude of 37,000 ft. It equals to 6 μSv/h (Photo credit: Mark Ramsay, Ionactive Consulting Limited, United Kingdom)

Photo 7.9 A particle detector in the Pampas is shown here. A tank with 12 m^3 of highly pure water is equipped with light sensors that detect the weak so-called Cherenkov light that is emitted by energy-rich particles as they pass through the water. Each tank is operated autonomously with solar electricity (about 10 W), a Global Positioning System (GPS) receiver for time synchronization, and radio transmission of the data to the central station (Photo credit: Pierre Auger)

Photo 7.10 This picture shows particle detectors. To reduce costs, the mesh of these particle detectors is rather coarse. They are located at a distance of 1.5 km from each other. The photo shows some of the water tanks displayed in Photo 7.9 (Photo credit: Karlsruhe Institute of Technology, Germany)

An increase in the number of *cancroids* was also recorded among pilots in the United States (Nicholas et al. 1998). An examination of 265 pilots in Iceland showed that skin cancer is found among them 25% more often than it is in other population groups (Jansen et al. 2000).

The effects of cosmic radiation on human activities are illustrated by Photos 7.8–7.10.

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Internet Resources

http://info.med.yale.edu/psych/clinics/winterdep.html
http://resources.yesican.yorku.ca/trek/radiation/final/index_natural_par.html
http://www.jpnet.me.uk/school/radiation/source1.htm
http://www.magnitventil.ru/index.php?option=com_content&task=view&id=33&Itemid=42
http://www.mentalhealh.com/book/p40-sad.html
http://www.meteorcrater.com/Mcrater.htm
http://www.nmha.org/infoctr/factsheets/27.cfm
http://www.physics.isu.edu/radinf/natural.htm
http://www.psychiatry.ubc.ca/mood/sad/pcp_sad.htm
http://www.rambler.ru/news/science/spacenews/10518577.html
http://www.sec.noaa.gov/info/RadHaz.html
http://www.sltbr.org/sadfag.htm
http://www.spaceweather.gc.ca/effectsgps_e.shtml
http://www.spaceweather.gc.ca/power_shtml
http://www.findarticles.com/cf_0/m3225/5_61/61432742/p1/article.jhtml
http://www.psychdirect.com/depression/d-treatmentguidelinesSAD.htm

Part II

Human Impacts on the Environment

8 Electric Power Industry

Abstract

The electric power industry is the branch of power engineering that includes the generation and transmission of electric energy. The key role of this branch is explained by the advantages of electric energy over other kinds of energy – advantages such as the relative easiness of its long-distance transmission, distribution between consumers, and conversion to other kinds of energy (mechanical, thermal, chemical, optical, and so on). A distinctive feature of electric energy is that its generation and consumption are relatively simultaneous because the electric current propagates through the network with a speed close to the speed of light. In the foreseeable future, it will remain a principal kind of energy, providing engineering progress in all spheres of the lives of people. Electricity is generated by power plants through the use of energy carriers or the conversion of other kinds of energy. For example, heat in thermal power stations transforms water into steam, forcing the rotors of steam turbines. These turbines are connected to the rotors of generators, in which the mechanical energy of the turbines is transformed into electrical energy. Solar power stations transform the energy of sun rays into electrical or thermal energy, for example.

Keywords

Electricity • Electric power plants • Hydropower • Solar energy • Economic loss • Natural components • Environmental impacts • Land condemnation • Energy transformation

8.1 Hydropower Structures

Hydropower engineering is a power industry based on the use of hydraulic power for generation of electric energy in hydroelectric power plants (HPPs).

The HPPs are widely distributed. They *produce* approximately 20% of the world's electricity, and account for about 88% of electricity from renewable sources. Worldwide, an installed capacity of 777 GW supplied 2,998 TWh of hydroelectricity in 2006 (http://www.eia.doe.gov). More than a half of the total world's storage falls in *seven countries*: Russia, the United States, Canada, China, Brazil, India, and Mexico (Avakyan and Lebedeva 2002).

The *major structures* of an HPP include a dam, a storage reservoir, channels, pressure pipelines, distribution devices, and other structures; however, the major changes in the environment are caused by the construction of storage reservoirs. Summary total capacity of reservoirs for countries is shown in Fig. 8.1.

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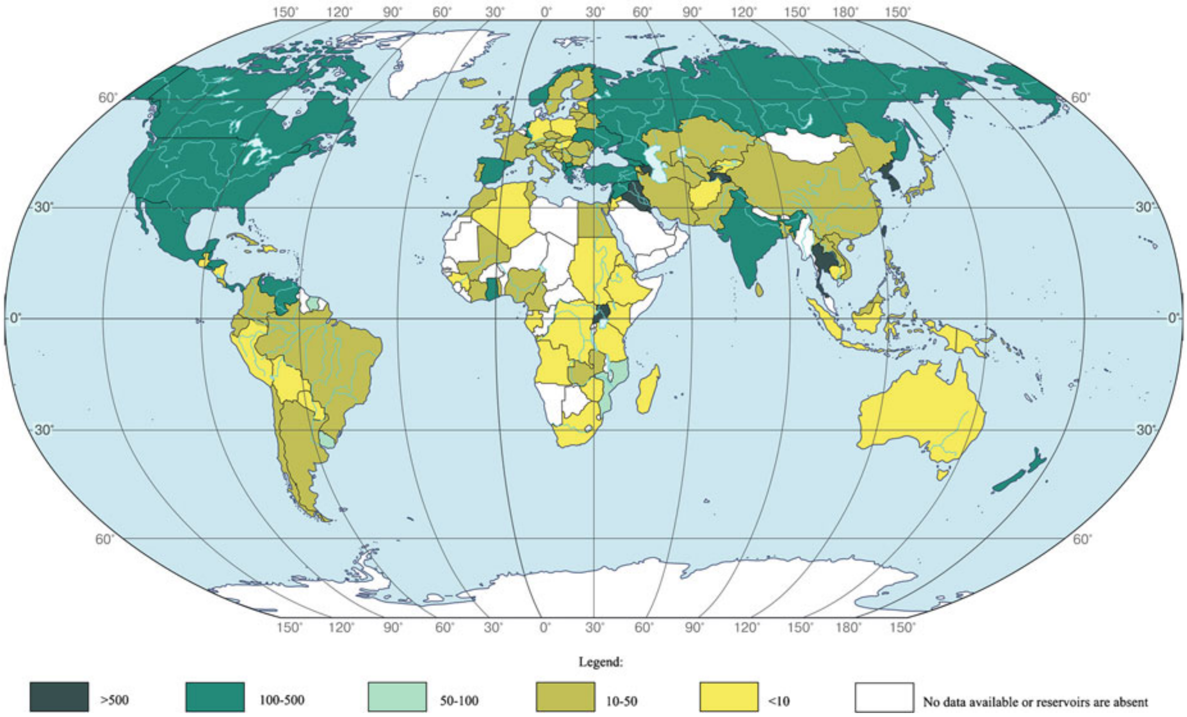

Fig. 8.1 Reservoirs of the world. Summary total capacity (by countries, million cubic metres per 1,000 km^2) (Resources and environment 1998. Reproduced with permission of Geography of the Russian Academy of Sciences)

Today, there are more than 50,000 dams above 15 m high, capable of holding back more than 6,500 km^3 of water, or about 15% of the total annual river run-off globally (Dams under debate 2006). Over 300 dams are defined as *giant* dams, which meet one of *three criteria* on *height* (higher than150 m), dam *volume* (more than 15 million cubic metres), or reservoir *storage* (more than 25 km^3) (Nilsson et al. 2005).

The effects of a storage reservoir extend for the whole catchment basin up to the mouth of the river where it reaches the sea. The *major damage* is caused by flooding of the land, changes in the regime of river run-off below a dam, and the backwater effect, which, in turn, involve effects on practically all natural components. Basically, these *components* include the following: (1) condemned land; (2) surface waters; (3) vegetation; (4) soils; (5) animal kingdom; (6) atmosphere; and (7) geologic environment.

Hydropower engineering is high on the list of activities that involve the *withdrawal of lands* from other uses. More than 95% of the land area used for energy facilities is condemned land used for hydropower facilities (Lyalik and Reznikovsky 1995). Such significant condemnation of lands creates strong *socio-economic* impacts related chiefly to forced resettlement. For example, construction of the *Aswan High Dam* required the resettlement of 120,000 local residents (Ibrahim 1983); the *Pa-Mong Dam* in Vietnam led to the resettlement of 450,000 (Canter 1996); and construction of the *Three Gorges Dam* in China resulted in the resettlement of 1.2 million people (Steil and Yuefang 2007). In total, the number of displaced people is estimated at 40–80 million (Dams under debate 2006). As a result of flooding of land, historical, architectural, and archaeological monuments often disappear.

The influences on *surface waters* are diverse. The establishment of a storage reservoir results in changes not only in the natural hydrological regime of a river, but also in other related natural processes (hydrochemical, hydrobiological, and so on). These changes are first of all caused by river run-off redistribution in the course of a particular period, usually a year.

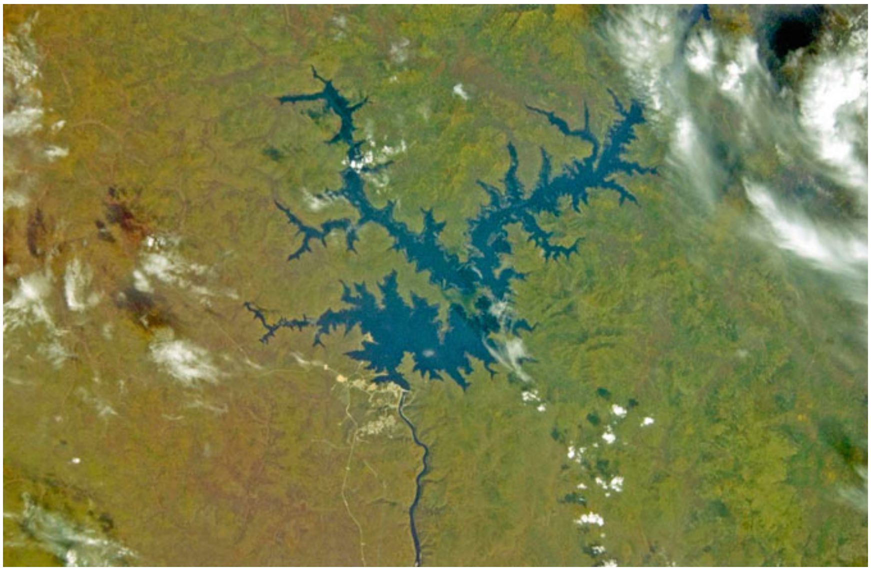

Photo 8.1 Hydropower engineering is high on the list of activities that involve the withdrawal of lands from other uses. More than 95% of the land area used for energy facilities is condemned land used for hydropower facilities. This space image shows the storage reservoir of the Bureyskaya Hydro Power Plant in the Far East of Russia. Its area is 740 km^2; length, 234 km; and width, about 5 km. The total and usable capacities of the reservoir are 20.94 and 10.7 km^3, respectively (Photo credit: Russian Space Agency)

Photo 8.2 Over 300 dams are defined as giant dams, which meet one of three criteria on height (higher than 150 m), dam volume (more than 15 million cubic metres), or reservoir storage (more than 25 km^3). Shown here a dam of the Sayano–Shushenskaya hydroelectric power station (Russia) has a height of 246 m and a volume of 9 million cubic metres, creating a storage reservoir with a volume of 31.3 km^3 (Photo credit: A.M. Panichev, Pacific Geographical Institute, Vladivostok, Russia, 1987)

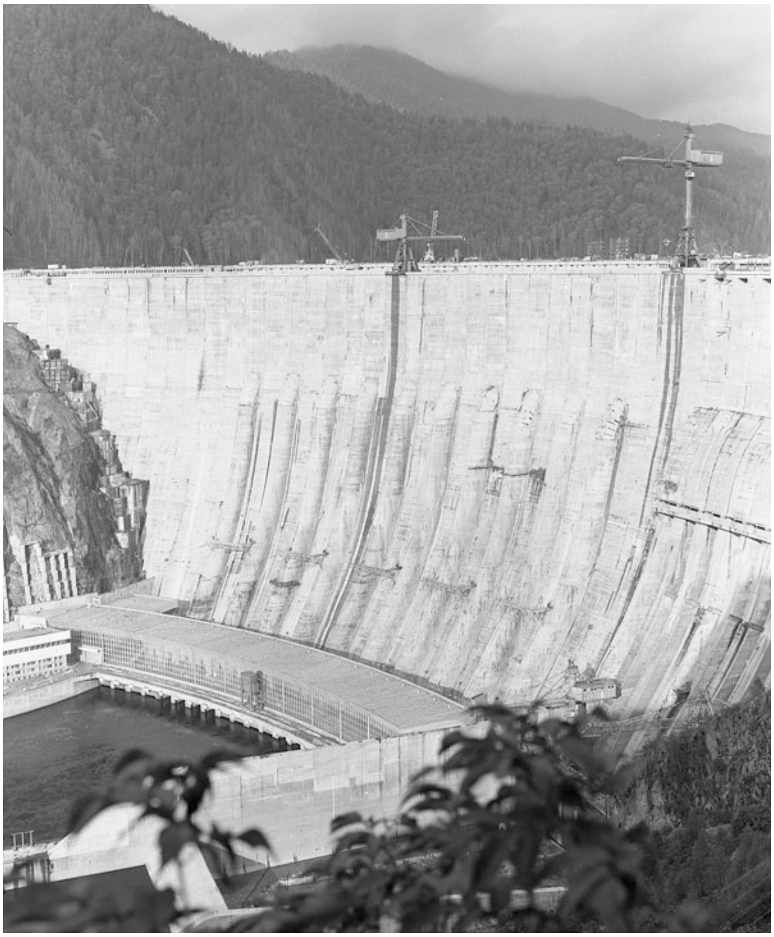

Photo 8.3 Influences on vegetation of hydroelectric power stations include flooding of forests when a storage reservoir is being filled. Flooding causes the decay of organic matter, with emissions of methane and carbon dioxide, which in turn result in mass fish mortality due to reductions in the oxygen content of the water. They also contributes to the greenhouse effect. The forest flooded in the course of filling the Sayano-Shushenskaya hydroelectric power station (Russia) storage reservoir is shown (Photo credit: A.M. Panichev, Pacific Geographical Institute, Vladivostok, Russia, 1987)

Changes in the character of *riverbed evolution* are expressed as *lowering* of the elevation marks of bars and *rises* in the bottoms of river reaches; that is, a flattening of the riverbed profile occurs (Lyalik and Reznikovsky 1995). A storage reservoir changes the *thermic regime* of a river within downstream sections as warmer water than that in the river flows into it in autumn and colder water flows into it in spring; differences reach, on average, 2–4°C. Sometimes, the *lengths* of zones of influence are several hundred kilometres (Avakyan et al. 1987).

Irregularities in daily and weekly water flow rate conditions result in abrupt variations in the *ice regime*. In regions with cold climates, this often causes autumn and spring ice jams and, thereby, water level rises. Changes in hydrochemical conditions are expressed as an alignment of the chemical composition of waters by seasons as well as reduction in the drainage of *biogenic substances*.

For example, the inflow of fertile silt to the Nile River delta and eastern Mediterranean Sea practically stopped as a result of the construction of the *Aswan High Dam* (Goudie 1997). In this connection, the catch of sardines within the water area related to the Nile River decreased by 300 times. The construction of the *Nurek hydropower station* on the Vakhsh River stopped the annual influx of 1.3 million tons of humus to lands that used to be flooded, because the humus remains in the bottom sediments of the Nurek storage reservoir (Gorshkov 1992).

Variations in hydrological, hydrochemical, and thermal conditions, result in changes in the conditions under which *ichthyofauna* develop because the biomass of forage organisms decreases and the conditions of spawning, fattening, and hibernation of fish deteriorate (Avakyan et al. 1987). In turn, these changes influence the *vegetative* ground cover and the *animal* inhabitants of the river valleys and deltas.

In storage reservoirs, there is an abrupt *drop in water exchange* as compared with that in rivers. For example, in daily storage reservoirs it is observed

Photo 8.4 In small water courses, hydroelectric stations designed to supply electricity to small power users in remote areas are not infrequently constructed. The photo shows one such station on a branch of the Malaya Kema River (north-western Primorsky Krai, Russia) (Photo credit: A.M. Panichev, Pacific Geographical Institute, Vladivostok, Russia)

15–20 times a year, while in seasonal storage reservoirs it is observed only every 1–4 years (Lyalik and Reznikovsky 1995). Reductions in flow velocities cause the sedimentation of nearly all *tractional* load and a large portion of *suspended* solid particles on the bottom. On average, about 90–95% of drift remains in the storage reservoir, which results in their silting (Avakyan et al. 1987).

Depending on the conditions in a storage reservoir, the *water quality* may be either higher or lower than that in a river. The processes of natural *purification* – including sedimentation, settling, dilution, disintegration of organic substances, and so on – can lead to improvements in water quality. Water quality may deteriorate due to slowdowns in water exchange, development of living organisms, and processes of oxygen and thermal stratification. Storage reservoirs are more subject to contamination as compared with rivers (Lyalik and Reznikovsky 1995).

In tropical areas, the *water quality* is, as a rule, worse. The carriers of many diseases (such as malaria and schistosomiasis) experience favourable living conditions, which results in increases in the morbidity and mortality of people (Golubev 2006).

Transformation of the banks of storage reservoirs is especially intense over the first years after they are filled. The losses of land due to bank transformation may be considerable. For example, about 5,000 ha – that is, approximately 2% of the flooded area – were lost near the Tsimlansky storage reservoir (Russia) (Lyalik and Reznikovsky 1995).

One more consequence of constructing storage reservoirs is an *under-flooding* of lands due to rising groundwater levels. In different storage reservoirs, such territories amount to 3–15% of the flooded area (Storage reservoirs 1986). The under-flooding, in turn, causes changes in the species composition of vegetation within the coastal zone.

Influences on *vegetation* are expressed as flooding of forests when a storage reservoir is being filled. For example, more than 20 million cubic metres of wood appeared to be under water after construction of the Ust-Ilimsky hydropower station (Russia) (Engineering ecology 2003). The creation of storage reservoirs also results in fundamental changes in higher *aquatic vegetation and phytoplankton*. For many storage reservoirs, the rapid development of blue-green algae is a serious problem (‘water bloom’).

Photo 8.5 The Teton Dam was an earthen dam built on the Teton River in south-eastern Idaho (United States). When the reservoir was being filled for the first time, the dam suffered a catastrophic failure on 5 June 1976. The collapse of the dam resulted in the deaths of 11 people and 13,000 head of cattle. The photo shows water pouring out of the reservoir of the Teton Dam following its catastrophic failure (Photo credit: U.S. Department of the Interior, Bureau of Reclamation)

The effects on *soils* are related to their under-flooding in the vicinity of the reservoir and lowering of the ground-water line downstream of the dam due to decreases in the area of the flood plain (Reservoir storage 1986).

Filling a reservoir has an adverse effect on *fauna*. Often, the fast flooding of a territory causes the loss of many animals. Many species of animals (snakes, shrews, moles, hedgehogs, and so on) move too slowly to obtain refuge from the rising water. In addition, many temporary islands appear in valleys with complex relief at the beginning of the flooding, and many animals that seek refuge on them perish later on.

Because lands that previously were inundated primarily in spring may become flooded permanently, the richest biogeocenoses are destroyed, which results in the *disappearance of the habitats* of many animals. Birds and animals displaced from the flooded zone concentrate within a coastal area where the natural conditions are usually less diverse as compared with the submerged territory. Unfavourable water levels cause a decrease in the quantity of *waterfowl and wading birds* as well as of *semiaquatic animals*.

The construction of storage reservoirs significantly affects the *ichthyofauna*. Changes occur in things such as the rate of fish growth, the number and structure of populations, lifetimes, and reproduction and maturing conditions. The erection of dams on the majority of large rivers in the world disturbed the *migration paths* of valuable diadromous and catadromous fish (sturgeon, salmon, herring). Their spawning grounds proved to be inaccessible for spawners. The fish perish in the course of downstream migration through turbines and dams. Especially numerous losses take place in the high-pressure units as a result of barotraumas of the *air bladders* of fish when they move from the storage reservoir to the tailwater (Pavlov et al. 1999).

Effects on the *atmosphere* are expressed as changes in the climate of adjacent territories. On the great plain storage reservoirs, the climatic variations affect the territory commensurable with the water surface area; mountain storage reservoirs exert little effect on the climate. All climatic variations are substantially related to the growth of total *radiation* and changes in the water body radiation balance, as well as to the larger *heat capacity* of a water body as compared with that of the land.

In essence, the variations consist of a decline in the climate *continentality*. The diurnal temperature variations become smooth, air humidity increases, the wind speed and direction change, the number of calm days sharply decreases, and the conditions of cloudiness and amount of precipitation over the water area decrease slightly, while those over the coast increase during the ice-free period of the year. In case of the existence of ice openings in the downstream water, the frequency of *fogs* increases in winter.

Storage reservoirs affect the climate through the discharge of *greenhouse gases* (especially carbon dioxide gas and methane) into the atmosphere. This effect is maximal in northern areas where great areas of peatlands prove to be within the flooded area (Louis et al. 2000).

The influence on the *geological environment* is expressed as increases in seismicity. It is well known that the construction of great storage reservoirs in areas of tectonic activity results in *earthquakes*. Some *examples* of the interrelationships between storage reservoirs and earthquakes are as follows: Kremasta in Greece, Koyna in India, Kariba in Zimbabwe and Zambia, Monteynard in France, and Nurek in Tajikistan. Earthquakes with magnitudes of 6.0 or greater have been observed in these areas (Mekkawi and Schnegg 2004; Nikolayev and Vereshchagina 2006).

Thus, storage reservoirs affect practically all of the components of the natural environment. The character of the effects of a storage reservoir is, in many respects, related to its parameters and morphology (Avakyan et al. 1987). For example, the *dimensions* of a storage reservoir and its *configuration* determine the amount of water evaporation, flooded area, intensity of bank transformation, and other characteristics. The *total storage amount* determines the variations in characteristics such as microclimate, seismicity, and hydrobiological processes. The *depth* of a storage reservoir influences the intensity of bank transformation, groundwater level changes, infiltration losses, and other parameters.

Most probably, the effects of storage reservoirs on *surface waters*, as well as on *ichthyofauna, soils, and vegetation* of adjacent territories, should be recognized as most important.

Hydroelectric power plants are quite safe sources of electric energy, but emergency situations related to them are not uncommon. The *failure of dams* is most dangerous. The *largest catastrophic failure* of a dam was that of the Banqiao Dam (Henan Province, China) in 1975; the disaster killed 26,000 people (http://en.wikipedia.org/wiki/Dam_removal). The *greatest financial loss* (almost US$2 billion) was recorded in the course of the 1976 Teton Dam failure in the Colorado River basin (Idaho, United States) (Malik 2005).

The effects of hydroelectric power plants on the environment are illustrated by Photos 8.1–8.5.

8.2 Thermal Power Structures

A *thermal power station* is a power station that uses the energy of combustion of any fuel to generate electric energy. This branch is the principal supplier of electric energy. In 2006, it provided 67% of the total electric energy generated in the world (http://www.iea.org/textbase/nppdf/free/2008/key_stats_2008.pdf). The prevalent kind of fuel is coal, followed by gas, black oil, and peat.

Thermal power stations influence the following environmental *components*: (1) air; (2) surface waters; and (3) soils. Thermal and noise effects are also of some importance. Thermal power stations exert indirect effects on other components of the environment (e.g. vegetation, underground waters).

The effects on the *atmosphere* are expressed as consumption of enormous amounts of oxygen and contamination of the air. The *major contaminants* discharged to the atmosphere include flying dust (ash), sulphur oxides, nitrogen oxides, and carbon dioxide. The contribution of thermal power engineering to air basin contamination is estimated at 27%. Solid particles account for 31% of the total amount of discharges, while sulphur dioxide and nitrogen oxides account for 42% and 24%, respectively (Golubev 2006).

Every year, thermal power stations discharge into the atmosphere more than 200 million tons of *carbon oxides*, 50 million tons of different *hydrocarbons*, 150 million tons of *sulphur dioxide*, more than 50 million tons of *nitrogen oxides*, and 250 million tons of fine *aerosols* (Kazansky et al. 1992). Depending on the fuel composition, other pollutants are also released into the air. For example, in the course of coal combustion, 280,000 ton of *arsenic* and 224,000 ton of *uranium* are released into the atmosphere every year (Khristoforova 1999).

Some *elements* are discharged into the atmosphere in amounts exceeding their extraction from deposits. For example, emission of molybdenum from coal-fired power plants is more than 3 times the amounts

Photo 8.6 The effects of thermal electric power stations on the atmosphere are expressed as consumption of enormous amounts of oxygen and contamination of the air. The major contaminants discharged to the atmosphere include flying dust (ash), sulphur oxides, nitrogen oxides, and carbon dioxide. The releases of a thermal electric power station (Moscow, Russia) into the atmosphere are shown (Photo credit: V. Kantor, Greenpeace Russia, 15 April 2003)

Photo 8.7 This picture shows long-term effects of coal burning in Glasgow, Scotland. The building on the right was recently cleaned (Photo credit: Marli Bryant Miller, Department of Geological Sciences, University of Oregon, United States)

extracted from deposits; arsenic, 7 times; uranium and titanium, 10; aluminium, iodine, and cobalt, 15; mercury, 50; lithium, vanadium, strontium, beryllium, and zirconium, in the hundreds; and gallium and germanium, in the thousands (Engineering ecology 2003). Coal burning released more metal than is carried away by river run-off (vanadium, 400 times; molybdenum, 35; and carbon, 20) (Perelman and Kasimov 1999).

A present-day coal-fired power plant generating 2.4 million kilowatts of electricity consumes about 20,000 ton of coal a day, and discharges 680 ton of sulphur dioxide, 200 ton of nitrogen oxides, and 120–140 ton of flue ash into the environment (Khotuntsev 2002).

It should be noted that the volume released determines only the amount of fallout contaminants. Reactions taking place in the atmosphere alter the emitted compounds. Some emissions react with each other or natural elements in the atmosphere and are transformed into more *dangerous* compounds, while others, on the contrary, become *safe*. For example, nitrogen oxides, after oxidation to dioxides, fall to the ground in the form of fixed nitrogen, replacing common fertilizers in super-alkaline soils.

The effects on *surface waters* include the following: (1) changes in the qualitative condition of water bodies and (2) influence on the amount of surface water. Changes in the qualitative condition occur in the case of discharge to water bodies of waste water with increased concentrations of contaminants.

The major contaminants released into water bodies are *mineral salts* (mainly sulphates and chlorides) and *oil products* (e.g. sulphur fuel oils and kerosene) and other pollutants (such as corrosion products, solutions of inorganic acids, and other compounds). The danger of contamination of surface waters with *soluble salts* is that they, in contrast to other pollutants (e.g. solid particles and organic, toxic, and surfactant species), are not subjected to the effects of environmental processes (e.g. deposition, decomposition, and uptake by living organisms); therefore, they can be extracted only by artificial techniques (Lyalik and Reznikovsky 1995).

Pollution by oil products is characteristic mainly of *oil-fired thermal power plants*, and it is insignificant on the whole. Other pollutants are delivered to water bodies with waters of cooling and hydraulic ash removal systems, spent solutions after the chemical treatment of heat and power equipment, and so on. On the whole, the effects of thermal power engineering on the qualitative condition of water bodies are not too great.

The *quantitative effects* are expressed as an irrevocable withdrawal of water resources. The major water losses take place in the operation of cooling systems (water cooling towers, cooling ponds, and cooling passages). For example, about 2.5% of the water circulating in a water cooling tower is lost due to evaporation (ReVelle and ReVelle 1995).

The influences of thermal power engineering on *soils* also can be subdivided into quantitative and qualitative. The *former* are expressed as a condemnation of land for construction of the power plants (basic structures, cooling storage reservoirs, ash disposal areas, etc.). For example, more than a 1,000 ton of slag and ash are formed every day in a coal-fired power plant with an output of 1 million kilowatts, and about 1 ha a year is needed for their storage (Arzhanov 1994).

Changes in *soil quality* are caused by dust rising from the ash disposal area surface, settling of atmospheric emissions directly on the soil, and washout of toxic matter from vegetation when it rains.

Thermal pollution of the natural environment should be discussed separately. For example, only 30–35% of the energy generated as a result of fuel combustion in a coal-fired power plant is delivered to consumers. About 10% of the heat goes to the atmosphere, while 50–55% of the energy is removed in the course of water cooling of condensers (Lyalik and Reznikovsky 1995). The discharge of warm water may result in changes in the species composition of the aquatic flora and fauna, because conditions become favourable for the reproduction of thermophiles.

The negative aspects of such effects include the development of organisms (bacteria, algae, protozoa) in excess, which can contribute to water *quality degradation* and depression of the growth of some species of aquatic animals and fish. *Positive* aspects include the species enrichment of hydrobionts, improvement of forage resources for fish, acceleration of pubescence of aquatic animals, and prevention of winter fish kill.

The effects on *vegetation* are caused mainly by the contact of green parts of plants with atmospheric pollutants and soil degradation. Soil contamination has

Photo 8.8 The Kingston Fossil Plant coal fly ash slurry spill occurred on 22 December 2008. An ash dike ruptured at an 84 acre (0.34 km^2) solid waste containment area at the Kingston Fossil Plant in Roane County, Tennessee (United States). As a result, 1.1 billion gallons (4.2 million cubic metres) of coal fly ash slurry were released. Contamination of land and waterways and destruction of homes occurred. It was the largest fly ash release in US history. This orthographic aerial photograph was taken the day after the event (Photo credit: Tennessee Valley Authority, 23 December 2008)

marked effects on crop capacity. Within a 2–3 km zone around a power plant, reductions of yields due to emissions of ash and sulphur dioxide are as follows: rye, 15–28%; wheat, 18–26%; barley, 16–34%; oats, 30–45%; potatoes, 17–35%; fodder root crops, 15–30%; corn, 25–50%; and grasses, 14–25% (Bretschneider and Kurfürst 1989).

From the viewpoint of the effects on the environment, thermal power engineering is characterized as having the most negative consequences among all energy industries (Govorushko 2003a).

The effects of thermal power engineering on natural components are illustrated by Photos 8.6–8.8.

8.3 Nuclear Power Plants

A *nuclear power plant* (NPP) is a power plant that transforms the energy of nuclear disintegration in a reactor into electricity. In 2009, these power plants provided 15% of all electric energy (http://en.wikipedia.org/wiki/Nuclear_power).

In 2007, there were 439 nuclear power reactors in operation in the world, operating in 31 countries. The leaders in total generation are the United States, France, Japan, Russia, and Germany. As for percentage of total national electric power generation, the countries rank in the following order: France (76.2%), Belgium (53.8%),

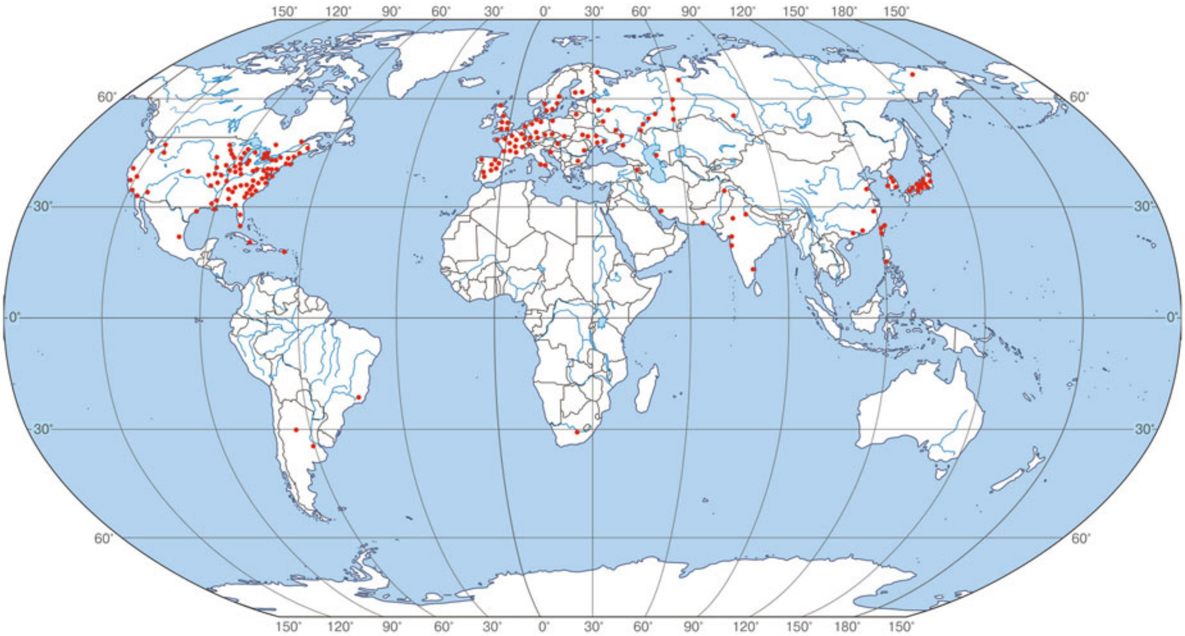

Fig. 8.2 Nuclear power plants of the world (Maksakovsky 2006, vol 1. Reproduced with permission of V.P. Makskovsky)

Photo 8.9 The thermal pollution from nuclear power plants is greater than that from thermal power stations. Heat is released by NPPs through condensation systems with cooling water and with ventilation air. The photo shows cooling towers of a nuclear power plant in Cattenom, France (Photo credit: http://en.wikipedia.org/wiki/Nuclear_power, 11 March 2007)

Ukraine (47.4%), Armenia (43.5%), and Sweden (42.0%) (http://en.wikipedia.org/wiki/Nuclear_power_by_country). Global distribution of nuclear power plants is shown in Fig. 8.2.

The effects of nuclear power plants on nature can be divided into three stages, each of which has its own complex of factors. During the first stage (the NPP *construction* stage), the major influencing factors are physical transformation of the landscape within the construction site and around it, including the construction of hydraulic structures for providing the NPP with cooling water, and noise pollution. During the second

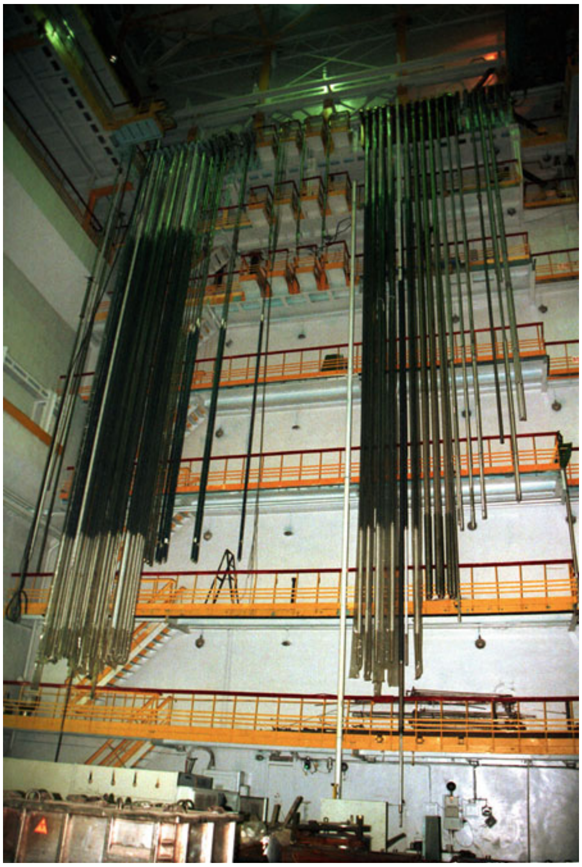

Photo 8.10 In the course of nuclear power plant operation, radioactive wastes of three kinds are produced: (1) spent fuel (fuel elements filled with compressed, sintered pellets of uranium dioxide); (2) waste products of reactor operation (wastes from cleaning of heat transfer agents from radioactivity, control rods, and so on); and (3) dismantled waste products. The fuel elements in the reactor hall of a Leningrad nuclear power plant (Russia) are shown (Photo credit: V. Kantor, Greenpeace Russia, October 1997)

stage (NPP *operation* stage), radioactive, thermal, and chemical pollution are major factors. During the third stage, after the NPP is *closed down*, the nuclear reactor and production facilities are sources of radioactivity over extended intervals.

The effects on the environment related to the *first* stage are, in many respects, the same as in the case of construction of other enterprises. These effects include noise and dust pollution due to blasting operations involved with construction and the laying of transportation routes and communications systems. The construction of water reservoir-coolers results in the same consequences as construction of small hydropower stations.

While NPPs are *operating*, the following effects are observed: (1) radioactive pollution of natural components (especially the atmosphere and surface waters); (2) thermal pollution of the water reservoir-cooler and underground waters; (3) chemical pollution of the atmosphere, soils, and water bodies; (4) under-flooding of territory; and (5) impacts on hydrobionts.

The major sources of *atmospheric* pollution with radioactive substances are as *follows* (Protection of the environment 1993): (1) combustible material nuclear fission (supplies inert gases such as xenon and krypton as well as radioactive iodine); (2) impact of neutron currents on the heat carrier of the primary-coolant system and ambient air; and (3) disturbance of the fuel element cans. A number of auxiliary facilities are also sources of radioactivity.

The contribution to *hydrospheric* pollution is made by subactive waters (waters of low radioactivity) of the *following systems*: (1) primary coolant circuit (waters of cooling and fuel assembly transfer ponds); (2) control and protection system loop; (3) waters forming in the course of decontamination of the reactor plant rooms; (4) flushing waters used in the course of equipment deactivation; (5) waters of sanitary inspection rooms and special laundries; and (6) waters discharged by radiochemical laboratories. Under conditions of normal NPP operation, a volume of tritium in the water body silts increases 20–50 times as a result of water discharge (Alekseenko 2005).

The radioactive contamination of *soils* and *vegetation* occurs when the radionuclides fall out to the Earth surface from the atmosphere. Depending on the landscape biochemical conditions, the radioactive contamination may accumulate or disperse.

It should be noted that, under conditions of *normal* operation, total emissions of radioactive substances are essentially lower than maximum permissible levels. According to requirements of the International Atomic Energy Agency (IAEA), they should not exceed 5% of the natural radiation background (ReVelle and ReVelle 1995). In this characteristic, they rank below coal-fired power plants; however, the serious environmental problem is radioactive waste storage and disposal.

In the course of NPP operation, radioactive wastes of three *kinds* are produced (Lyalik and Reznikovsky 1995): (1) spent fuel (fuel elements filled with compressed, sintered pellets of uranium dioxide); (2) waste products of reactor operation (wastes from cleaning of heat transfer agents from radioactivity, control rods,

Photo 8.11 This true-colour picture shows the Chernobyl nuclear power plant. The large body of water is a 12 km long cooling pond, and water channels run through the network of reactor-related buildings west of the pond. Reactor number four appears on the west end of a long building north-east of an L-shaped water channel. Mixing with the network of abandoned buildings, water channels, and roads, areas of green appear – a testament to the vegetation that was growing around the site some 20 years after the accident (Photo credit: Jesse Allen, NASA Earth Observatory, 5 August 2009)

and so on); and (3) dismantled waste products. Depending on the disposal method, contamination of different natural media (surface and underground waters, geological environment, etc.) is possible.

The *thermal* pollution from NPPs, which is greater than that from thermal power stations, is important (Yablokov 2001). The other difference lies in the fact that the heat released by an NPP is created through the condensation system with cooling water and only partially with ventilation air; therefore, this thermal contamination does not significantly affect the atmosphere and instead extends to surface and underground waters.

For example, four million cubic metres of fresh and sea water per minute are discharged from NPP water cooling systems in the United States, and temperatures of process water exceed the *temperatures* of natural waters by 5–15°C (Dynamics of marine ecosystems 2007). On the site of the Kola NPP (Russia), located within the Arctic Circle, the temperature of underground waters increased from 6°C to 19°C near the main building (Vronsky 2007).

Nuclear power plants are also accountable for *chemical* pollution of surface waters. These pollutants can be subdivided into three *groups* (Lyalik and Reznikovsky 1995): (1) inorganic matter not exceeding the maximum permissible concentrations (MPCs) in waters (sulphates and chlorides of calcium, magnesium, and sodium); (2) toxic substances whose concentrations exceed their MPCs in water bodies (salts of iron, copper, and zinc, fluorine compounds, etc.); and (3) matter affecting biological oxygen demand values (ammonium salts, nitrates, sulphides, etc.).

The contamination of *air* in the course of NPP operation is minor, caused by volatile substances and dust emitted from different processing solutions and stored solid waste, and combustion of organic fuels (gas, fuel oil, coal) used in heaters and other plants (Babayev et al. 1984).

The effects on *hydrobionts* occur due to thermal contamination of the aquatic environment and their passage through water intakes. For example, the total number of fish involved in the water intakes in an NPP on Lake

Erie (with water flow of about 85 m^3/s) can exceed 500 million individuals a year. In the Leningrad NPP (Russia), 50% of zooplankton is killed when it enters the water intakes (Kryshev and Ryazantsev 2000).

The influence of nuclear power plants on natural components that occurs during *dismantling* is not clearly understood because we have little experience in decommissioning. The International Atomic Energy Agency recommends *three variants* for the decommissioning of NPPs (Lyalik and Reznikovsky 1995): (1) storage of the object taken out of service under inspection; (2) partial dismantling of equipment with restricted use of the industrial site; and (3) complete removal of the plant. In any event, environmental contamination with radionuclides is possible.

As for the *economic impact* of ecological damage caused by NPPs, there are few data. For example, the damage to fish resources caused by two NPPs (Sizewell A and B) located on the eastern coast of England reached 520,000 lb sterling a year; water for cooling the plants was obtained from the North Sea (80 m^3/s for both NPPs combined) (Turnpenny and Taylor 2000).

The effects of nuclear power plants on the environment are illustrated by Photos 8.9–8.11.

8.4 Non-traditional or Alternative Power Structures

The category of *non-traditional* or *alternative power structures* includes power plants that use renewable energy sources. Strictly speaking, hydraulic power is also a renewable source, but it, along with thermal and nuclear power, is generally categorized as traditional power engineering. One can identify the following *sources* of energy used in this kind of electroenergetics (Gogolev 2009): (1) solar (photovoltaic power); (2) wind energy; (3) energy of the Earth interior (high-temperature geothermal energy); (4) ocean energy (energy of tides, waves, currents, temperature differences); and (5) energy of biomass (for electrical energy generation, a biogas is used).

The world technological *capacity* of renewable energy sources is estimated on the whole as follows (in billion tons of equivalent fuel a year): biomass, 5.6; hydraulic power, 2.8; wind energy, 2.8; geothermal energy; 1.9; thermal sea energy, 0.9; tidal energy, 0.04; solar cells and collectors (decentralized), 2.0; and solar power stations, 4.3. The total value is 20.3 billion tons of the equivalent fuel (Environmental protection 1993).

The *total power* generated by all non-traditional sources by the end of 2008 was 280 GW, including the following (gigawatts): wind power, 121; small hydropower, 85; biomass power, 52; solar photovoltaic, grid-connected, 13; geothermal power, 10; concentrated solar thermal power (CSP), 0.5; and ocean tidal power, 0.3. The five countries that were *leaders* in the generation of electric power from these sources were China, the United States, Germany, Spain, and India (http://www.ren21.net/pdf/RE_GSR_2009_Update.pdf).

For the present, the proportion of power generated by *non-traditional sources* in the world is absolutely insignificant and reaches 3.4% of all power generated (http://en.wikipedia.org/wiki/Renewable_energy). However, its fast development (in 2006–2008, the year-to-year increase reached 14–15%) made it possible to achieve noticeable results, at least in some countries.

For non-traditional renewable energy sources, the following *features* are characteristic: (1) low specific energy density; (2) severe difficulties in power concentration; (3) non-uniformity in its distribution in time and space; (4) difficulties of its use in power systems as a replacement power source; (5) rather high economic costs, even considering the absence of fuel costs; (6) operational in automatic mode; and (7) possibility of local use in hard-to-reach areas (Vasilyev and Khrisanov 1991).

The extent of production engineering and costs of electric power generation from different renewable energy sources differ markedly. Some of them do not at present find *practical application*, although their potential is very high.

In particular, huge reserves of energy that can be transformed into electric power are concentrated in *ocean currents*. For example, the Gulf Stream carries a water volume exceeding 50 times the volume transported by all the rivers of the world. Based on the Gulf Stream, one could produce more than 100 million kilowatts of power. There are projects of such power plants in the Straits of Florida and Gibraltar and off the eastern shore of Japan (Kuroshio Current). However, the cost of such electric power is so far too high (Vasilyev and Khrisanov 1991).

Of all kinds of oceanic energy, the reserves of *osmotic energy* are the highest. For its generation, two solutions with different salt concentrations are needed. The source of such energy is at the mouths of rivers. The world's first osmotic plant, with a capacity of 4 kW, was opened by Statkraft on 24 November 2009 in Tofte, Norway (http://en.wikipedia.org/wiki/Osmotic_power).

The environmental consequences of operation of *salt power plants* are as follows (Vasilyev and Khrisanov 1991): (1) damage to living organisms in the course of water extraction or on membranes; (2) influence on freshwater species when waters of greater salinity are discharged; (3) variations in water circulation, which have an effect on the motion of nutrients and oxygen concentrations; and (4) penetration of toxic biocides used to prevent membrane contamination into the trophic chains.

Another important potential *source of energy* is the temperature drop caused by the fact that solar radiation does not penetrate deep into the ocean waters and, therefore, cold waters are at shallow depths below the warm layer. Power plants that take advantage of these temperature differences may use the heat of surface waters to transform cooling fluid into steam (vapour). The cold water from depths of some hundred metres will cool and condense this steam (vapour), forming a low-pressure zone to which new portions of steam (vapour) will move, rotating the turbines (Howard and Ramson 1982).

The use of similar power plants can result *in changes* in water circulation, disturbances in the biological balance, and climate change. In order to construct such power plants, large quantities of non-ferrous metals (magnesium, titanium, etc.) and new synthetic materials whose production is related to serious environmental contamination will be needed. The rise of deep waters rich in nutrients may have a favourable effect on organisms in surface waters.

At present, the *negative effects* of non-traditional kinds of power engineering are *small* because of the insignificant extent of the use of renewable sources and the low powers of plants. Increases in their share in the energy balance will undoubtedly result in increases in unfavourable environmental consequences.

The individual kinds of non-traditional power engineering are considered below.

8.4.1 Solar Power Structures

A *solar power plant* is an engineering structure used for conversion of solar radiation into electric power. Sunlight can be converted into electricity by using *photovoltaics*. World solar photovoltaic (PV) installations produced 2.826 GW peak in 2007, and 5.95 GW in 2008, a 110% increase (http://en.wikipedia.org/wiki/Photovoltaics#Overview).

Photovoltaics have mainly been used to power small and medium-sized applications, from the calculator powered by a single solar cell to off-grid homes powered by photovoltaic arrays. For *large-scale generation*, solar power plants are used. One example of such a facility is a complex of nine solar photovoltaic installations in California's Mojave Desert; the plant was constructed during 1984–1990.

Electricity and heat are produced from solar radiation in the following *ways*: (1) generation of electric power by using photocells; (2) conversion of solar energy into electricity by means of thermal machines, such as (a) steam engines (piston or turbine) using steam, carbon dioxide gas, propane-butane, or Freon and (b) Stirling engines (a kind of external combustion engine that may operate on any heat source); (3) solar power engineering (heating of a surface absorbing sun rays and subsequent distribution and use of the heat; focusing of solar radiation on a vessel containing water for subsequent application of the heated water in heating systems or steam electric generators); (4) thermo-air power plants (conversion of solar energy into the energy of an air stream directed to a turbo-generator); and (5) solar balloon power plants (generation of steam inside a balloon covered with a selectively absorbing coating that is heated by solar radiation).

The methods of solar radiation *conversion* are different and depend on the power plant construction. All solar power plants (SPPs) are subdivided into several *types*: (1) tower-base SPPs; (2) dish-shaped SPPs; (3) SPPs using photovoltaic cells; (4) SPPs using parabolic concentrators; (5) combined SPPs; and (6) balloon SPPs.

As of October 2009, the *largest* photovoltaic power plants in the world are (1) Olmedilla Photovoltaic Park, Spain (60 MW); (2) Strasskirchen Solar Park, Germany (54 MW); (3) Lieberose Photovoltaic Park, Germany (53 MW); (4) Puertollano Photovoltaic Park, Spain (50 MW); and (5) Moura Photovoltaic Power Station, Portugal (46 MW) (http://www.pvresources.com/en/top50pv.php).

Among the *advantages* of solar power plants are availability and inexhaustibility of the energy source. In order to meet today's needs of mankind for electric

Photo 8.12 The methods of solar radiation conversion are different and depend on power plant construction. All solar power plants are subdivided into several types: (1) tower-base SPPs; (2) dish-shaped SPPs; (3) SPPs using photovoltaic cells; (4) SPPs using parabolic concentrators; (5) combined SPPs; and (6) balloon SPPs. The photo shows a solar power plant in Serpa, Portugal, that use photovoltaic cells. The plant provides enough electricity to supply approximately 8,000 homes (Photo credit: http://en.wikipedia.org/wiki/Serpa_solar_power_plant, March 2006)

power, only 0.0004% of incoming solar radiation to the Earth is sufficient (Grachev 1995).

The often-declared environmental cleanness of solar power engineering is an *illusion*. From an environmental point of view, only the operation stage can be recognized to be relatively clean, and even that assertion is made with reservations.

The *negative effects* of solar power engineering become apparent in the *following*: (1) condemnation of land; (2) contamination of natural media in manufacturing materials for plants; (3) contamination of the environment with highly toxic chlorates and nitrites from working fluid leaks; (4) influence on vegetation and soils when they are shaded by solar concentrators; (5) changes in the heat balance and humidity in the vicinity of plants; (6) climatic effects of SPPs in space; (7) television and radio noises; and (8) thermal effects on the environment of cooling a condensate.

In addition, there is a theoretical probability that the all-round application of solar power engineering may change the *albedo* of the Earth surface and cause climate change (however, it is extremely unlikely at the current level of energy consumption).

The construction of solar power stations needs large *areas* of land. A power plant producing 1,000 MW in a hot, dry locality (such as west or central Australia) will need a total collector area of 13–25 km^2. This area is more than that occupied by an ordinary thermal power plant but less than the territory used for a plant and coal open-cut (Strauss and Mainwaring 1989).

Photo 8.13 The construction of solar power stations needs large areas of land. A power plant producing 1,000 MW in a hot, dry locality (such as west or central Australia) will need a total collector area of 13–25 km^2. This area is more than that occupied by an ordinary thermal power plant but less than the territory used for a plant and coal open-cut. The photo shows a tower-base SPP in Spain (Photo credit: http://en.wikipedia.org/wiki/Renewable_energy, 3 September 2007)

Photo 8.14 This photo shows the Solar Bowl in Auroville, India. It used solar energy for cooking. The ferrocement base of this stationary bowl faces south. It is 15 m in diameter and 7 m above ground level. The sun's rays, trapped by a huge hemispherical mirror, focus on a cylindrical boiler that follows the sun's position by means of a computerized tracking device. On a clear day, sufficient steam at a temperature of 150°C can be generated in this boiler to cook two meals a day for 1,000 people (Photo credit: http://en.wikipedia.org/wiki/Auroville)

The *indirect impact* of solar power engineering on the environment lies in the fact that it demands considerable resources. Enterprises manufacturing concrete, glass, steel, and other materials are needed to support the construction of solar power plants. The making of photoelectric cells for solar batteries demands a number of substances (silicon, cadmium, arsenide-gallium) that are hazardous to produce. In the case of wide development of solar power engineering, such indirect effects on the natural environment could be considerable.

The effects of solar power stations on the environment are illustrated by Photos 8.12–8.14.

8.4.2 Wind Power Structures

Wind energy is, at its core, the energy of the Sun converted into the kinetic energy of moving air masses. Wind energy was widely used even in ancient Egypt and the Middle East for driving mills and water-lifting devices. Over the period 1880–1930, about six million wind power plants (WPPs) in the United States were used for water pumping, operation of enterprises, and power generation (Howard and Ramson 1982).

The energetic potential of wind is quite high. For example, for *five countries* in the North Sea region (Germany, Great Britain, the Netherlands, Belgium, and Denmark), it exceeds the total volume of power consumption of these states (Kiseleva and Nefedova 2006).

Wind power stations convert wind energy into electric power. They consist of several wind turbines constructed in one locality. The great wind power stations can consist of 100 or more wind turbines. Sometimes, they are called wind farms. The world's first wind farm – consisting of 20 wind turbines rated at 30 kW each – was installed on the shoulder of Crotched Mountain in southern New Hampshire in December 1980 (http://en.wikipedia.org/wiki/Wind_farm).

Wind energy is used in more than 70 countries. The *leaders* in the generation and use of wind power are the United States, Spain, and China. At the end of 2008, wind power provided some 1.3% of global electricity consumed (http://www.wwindea.org/home/images/stories/pr_statistics2007_210208_red.pdf).

According to the where they are placed, the following *types* of wind power plants can be identified: (1) ground (wind turbines are usually installed in the hills); (2) coastal, or onshore (a small distance from the sea coast); (3) offshore (constructed at sea, within 10–12 km of shore); and (4) floating.

So far, *ground* wind power plants are the most common. The *greatest* of them (and of wind power plants on the whole) is the power plant in Roscoe, Texas (United States). It was put into operation on 1 October 2009, and includes 627 wind turbines. Total output is about 780 MW. The area of the power plant is approximately 400 km^2.

The largest *onshore* wind farm is Florida Power & Light's Horse Hollow Wind Energy Center, located in Taylor County, Texas. The Horse Hollow project operates 421 wind turbines and has a capacity of 735 MW (http://en.wikipedia.org/wiki/Wind_farm).

The greatest *offshore* wind power plant is the Middelgrunden power plant (Denmark), with an installed capacity of 40 MW. The plant was constructed in 2000 (http://en.wikipedia.org/wiki/Wind_power_in_Denmark). In late 2008, the total capacity of the offshore power plants in the world reached 1,471 MW. During 2008, 357 MW of offshore facilities were put into service. Great Britain is considered to have the greatest potential for creation of offshore wind power stations (Kiseleva and Nefedova 2006).

The first prototype of a *floating* wind turbine was constructed in December 2007. A wind turbine with a capacity of 80 kW was installed on an offshore platform within 10.6 nautical miles of the south Italy coast, in an area with a depth of 108 m. The world's first full-scale floating wind turbine, Hywind, is being assembled in the Åmøy Fjord near Stavanger, Norway (http://en.wikipedia.org/wiki/Floating_wind_turbine).

The *adverse effects* of wind power engineering include the *following*: (1) condemnation of land; (2) influence on the animal world; (3) noise impact; (4) visual impact; and (5) electrical, radio, and television noises.

Wind turbines cannot be too close to each other, because their capacities will be reduced due to *wind flow interference*. Therefore, their construction is related to considerable withdrawal of land. Wind power plants require approximately 0.1 km^2 of free space per 1 MW of power rating. Accordingly, a power station with a capacity of 200 MW will require about 20 km^2 of surface area (http://en.wikipedia.org/wiki/Environmental_effects_of_wind_power).

The influence on the *animal world* is expressed as danger to birds, insects, and aquatic organisms. The

Photo 8.15 According to where they are placed, the following types of wind power plants can be identified: (1) ground (wind turbines are usually installed in the hills); (2) coastal, or onshore (a small distance from the sea coast); (3) offshore (constructed at sea, within 10–12 km of shore); and (4) floating. A coastal wind power plant in Denmark is shown here (Photo credit: V. Kantor, Greenpeace Russia, 10 November 2000)

Photo 8.16 Middelgrunden is an example of an offshore wind farm. It is in the Øresund, 3.5 km outside Copenhagen, Denmark. When it was built in 2000, it was the world's largest offshore wind farm, with 20 turbines and a capacity of 40 MW. The farm delivers about 4% of the power for Copenhagen. While the wind at this location is not strong, it is very consistent, with the turbines generating substantial power over 97% of the time (Photo credit: http://en.wikipedia.org/wiki/Middelgrunden)

impact on the *ichthyofauna* is most dangerous over the period of *WPP construction*: disturbances in their habitats result in fish migration and fish kill. During the *operational period*, the effects of noises and vibration are not great, while cessation of navigation and fishing between the turbine supports may even have positive consequences. The effect on marine mammals (dolphins, seals, whales) is also minor.

During the *construction* period, the bottom deposits and structure of turbulent currents change, which has an adverse effect, first of all, on *benthic organisms*. The extent of the impact depends on the substrate

Photo 8.17 The effects of wind farms on birds are not great. Birds feel wind turbines at a distance of more than 1 km and avoid them. However, 0.3–0.4 fatalities per gigawatt-hour of electricity have been recorded, which correspond to about 70,000 birds a year for the territory of the United States. Some wind power stations discontinue operation during seasonal migration of birds. The picture shows birds navigating around wind turbines (Photo credit: B.K. Sovacool, National University of Singapore)

character; which is minimal in the case of bottom rock (Kiseleva and Nefedova 2006). During the *operational* period, when electric power is transmitted through a submarine cable, an excess of admissible values of strengths of electric and magnetic fields may cause fright reactions among fish and bottom-dwelling organisms, and, in this case, the cable will be a barrier to fish migration (Kadomskaya et al. 2006).

As for the effect on *birds*, it is minimal according to data obtained by European ornithologists. Birds feel wind turbines at a distance of more than 1 km and avoid them (Kiseleva and Nefedova 2006). According to data obtained by B.K. Sovacool (2009), 0.3–0.4 fatalities per gigawatt-hour of electricity have been recorded, which correspond to about 70,000 birds a year for the territory of the United States.

Nevertheless, cases in France are known in which the deployment of wind power plants was not approved due to concerns over damage to birds (Thonnerieux 2005). In addition, some wind power stations discontinue operation during seasonal migration of birds (http://en.wikipedia.org/wiki/Wind_farm).

There are also data on the death of *bats*. A study in 2004 estimated that over 2,200 bats were killed by 63 onshore turbines in just 6 weeks at two sites in the eastern United States (Arnett et al. 2005).

The *noise impacts* caused by wind turbines can be subdivided into mechanical and aerodynamic. The components responsible for the greatest noise are the generator; the swing actuator, which turns the top part of the wind power plant toward the wind; the gearbox; and the blades. Noise from some of these components is continuous, while that from the others occurs from time to time; however, noise is produced only when the turbine is operating. All in all, the noise of spinning turbines is relatively low as compared with that of other industrial sources.

Visual impacts also occur, but they are subjective. Many people believe that wind power stations improve the aesthetic qualities of the landscape; however, there are people who consider them to be unacceptable. In the United States, the Cape Wind Project in Massachusetts was delayed for years mainly because of aesthetic concerns (http://en.wikipedia.org/wiki/Wind_farm).

Wind power stations are the source of *radio* and *television interference*. In particular, because of the reflection of radio waves in the ultra-short band (USB) and microwave range by the rotating blades of wind power plants, the normal operation of airlines' navigational instruments is disturbed and reception of television transmissions is complicated (Engineering ecology 2003).

The effects of wind power stations on the environment are illustrated by Photos 8.15–8.17.

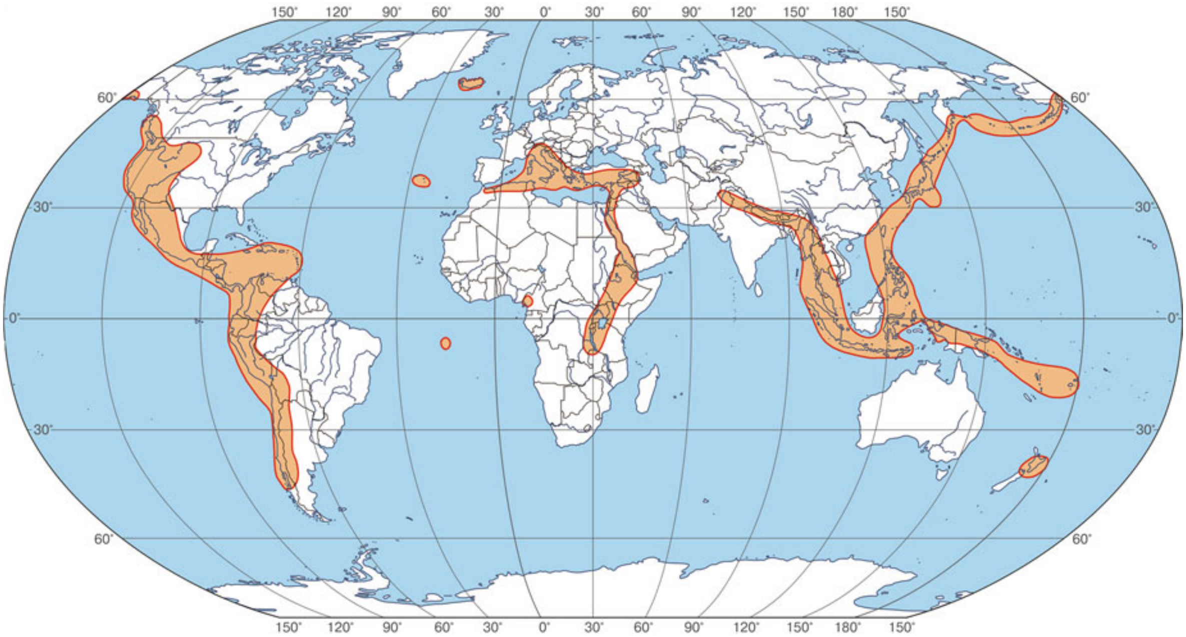

Fig. 8.3 World high-temperature geothermal provinces (Maksakovsky 2006, vol 1. Reproduced with permission of V.P. Maksakovsky)

8.4.3 Geothermal Power Structures

A *geothermal power plant* is a power station that converts the heat in the Earth into electric power. The virtue of geothermal power plants is their independence from atmospheric conditions associated with things such as the weather and the seasons.

The *first* large-scale geothermal electricity-generating plant opened at Larderello, Italy, in 1904, and it continues to operate successfully (Kagel et al. 2007). The *second* geothermal power station was built in the 1950s at Wairakei, New Zealand, *followed* by The Geysers in California (United States) in the 1960s (http://en.wikipedia.org/wiki/Geothermal_electricity).

At present, geothermal resources have been *identified* in some 90 countries, and there are *quantified records* of geothermal utilization in 72 countries. World high-temperature geothermal provinces are shown in Fig. 8.3. Electricity is *produced* from geothermal energy in 24 countries. A total of 56,786 GW/h of electricity was obtained from geothermal energy in 2005, accounting for 0.3% of worldwide electricity consumption (http://en.wikipedia.org/wiki/Geothermal_power).

The five countries that *led* in geothermal electricity production (gigawatt-hours per year) late in 2005 were (1) the United States, 17,917; (2) the Philippines, 9,253; (3) Mexico, 6,282; (4) Indonesia, 6,085; and (5) Italy, 5,340. The global installed capacity was 10 GW in 2007 (Fridleifsson et al. 2008). Based on the rated electrical power (in megawatts), the following countries occupied the leading positions in 2007: (1) the United States, 2,687; (2) the Philippines, 1,969.7; (3) Indonesia, 992; (4) Mexico, 953; and (5) Italy, 810.5 (Bertani 2007).

The *sequence of operations* of a geothermal power plant is as follows. Water is pumped through wells deep in the Earth where the rocks are very hot. Infiltrating into the rock joints and cavities, water gets warm with steam formation and rises back through the other, parallel wells. Thereafter, the hot water is delivered immediately to the power plant, where its energy is transformed into electric power through the use of one or more turbines and generators.

The *other variant* uses water heated to high temperatures as a result of natural processes. This water is pumped out of the Earth's interior or, due to high pressure, it rises by itself through drilled holes to the power plant.

At present, three *types* of geothermal power plants are used: (1) power plants operated on *superheated steam* (geothermal steam is directly used for rotation

Photo 8.18 Existing geothermal electric power plants emit an average of 122 kg of carbon dioxide per megawatt-hour of electricity. The atmospheric contamination per gigawatt-hour of electricity is small as compared with that for coal-fired power plants. The photo shows the Nesjavellir Geothermal Power Plant in Iceland (Photo credit: Gretar Ivarsson, Nesjavellir Island, 6 October 2006)

of turbines [dry steam]); (2) power plants operated on steam-hydrotherms (hot, deep water under high pressure is pumped into reservoirs at reduced pressure; the steam that is formed rotates a turbine [flash steam]); and (3) plants with a *binary cycle* (moderately hot water comes into contact with a second additional liquid having a lower boiling point; the heat of the geothermal water evaporates the second liquid, and the resulting vapours drive the turbines) (Kagel et al. 2007).

Geothermal power stations have major adverse effects on the following environmental *components* (Kubo 2003; Arnorsson 2004): (1) atmosphere; (2) geological environment; (3) surface and underground waters; (4) animal world; (5) condemnation of land; and (6) noise pollution.

The major contaminants of the *atmospheric air* are hydrogen sulphide, carbon dioxide, methane, ammonia, hydrogen, nitrogen, mercury vapour, radium, and radon (Gupta and Aggarwal 2001). These pollutants contribute to global warming and acid rain, and produce noxious smells if released. The emissions of hydrogen sulphide are the most hazardous.

Existing geothermal electric power plants emit an average of 122 kg of carbon dioxide per megawatt-hour of electricity (http://en.wikipedia.org/wiki/Geothermal_power). It is believed that the atmospheric contamination per gigawatt-hour of electricity is small as compared with that for coal-fired power plants. The power plants using binary cycles do not contaminate the atmosphere (Arnorsson 2005).

The effects on the *geological environment* are expressed as an increase in seismicity and subsidence of the Earth surface. A project in Basel, Switzerland, was suspended because more than 10,000 seismic events measuring up to 3.4 on the Richter scale occurred over the first 6 days of water injection (Deichmann et al. 2007). An increase in *seismicity* was also recorded after three geothermal power plants were put into operation in Kamchatka (Russia) (Chebrov and Kugayenko 2005).

Photo 8.19 The condemnation of land for utilizing geothermal power is also minor. A geothermal facility uses 404 m^2 of land per gigawatt-hour, while a coal facility uses 3,632 m^2/GWh. The Palinpinon Geothermal power plant in Valencia, Negros Oriental, Philippines, is shown here (Photo credit: Mike Gonzalez, 17 June 2006)

The construction of geothermal power plants can adversely affect *land stability*. Subsidence has occurred in the Wairakei field in New Zealand (Lund 2007) and in Staufen, southern Germany (Waffel 2008).

Surface waters are polluted when waste waters are discharged. The most toxic pollutants are arsenic, boron, and hydrogen sulphide, elements and compounds that frequently are present in poisonous concentrations in geothermal waters. Other elements and chemicals that may be present in harmful concentrations include aluminium, fluorine, ammonia, salts at high concentrations, and various heavy metals.

High concentrations of *heavy metals* are associated with high-temperature brines such as those at the Salton Sea in California and on the island of Nisyros, Greece. High *bromine* and *arsenic* concentrations are found in many geothermal systems associated with andesitic volcanism. Examples include Mount Apo in the Philippines and Achuapan in El Salvador. Boron-rich geothermal waters form upon reaction with marine sediments, such as at Ngwaha in New Zealand (Arnorsson 2005).

Consumption of water by geothermal power plants is insignificant. They use 20 l of fresh water per megawatt-hour versus over 1,000 l/MWh for nuclear, coal, or black oil plants (Lund 2007). Cases are known of contamination of *underground water* as a result of leakages in reservoirs and pipelines (Birkle and Merkel 2000).

The effects on the *animal world* are demonstrated in inhabitants of surface waters. For example, the geothermal heat carrier used in the New Zealand geothermal power plant Wairakei is discharged to the river of the same name. Concentrations of a number of heavy metals (e.g. mercury) in trout muscular tissue exceed many times the norm (Tomarov 1997).

The *condemnation of land* for utilizing geothermal power is minor. A geothermal facility uses 404 m^2 of land per gigawatt-hour, while a coal facility uses 3,632 m^2/GWh (Kagel et al. 2007). The *noise impact* is also minor. At the well drilling stage, it does not exceed 54 dB, while in the course of operation, noise levels are only 15–28 dB (Kagel et al. 2007).

The effects of geothermal power stations on the environment are illustrated by Photos 8.18 and 8.19.

8.4.4 Wave Power Structures

The *wave power* of the world ocean is estimated at 2.7 billion kilowatts (Engineering ecology 2003). For electricity generation, one can use wind-generated waves and surge. A peculiarity of sea disturbances is their *inhomogeneity over time*: maximum values are 5–11 times higher than average values (Vasilyev and Khrisanov 1991).

Spatial inhomogeneity is also characteristic of ocean disturbances. Wave power flows are maximal within the coastal zones at high latitudes, and the wave energy density in the southern hemisphere is much higher than that in the northern hemisphere. The coasts in the low latitudes are characterized by comparatively small energy flows. The boundaries of sharp changes in the wave energy flow values for the Pacific coasts of North and South America, as well as for the American coasts of the Atlantic Ocean, pass along 30°N and 30°S. For the eastern Atlantic coasts, the boundary of abrupt change in the energy flow in the southern hemisphere shifts to 10°S (Modern global changes 2006, vol 2).

The average maximal *density* of wave energy is 40 MW/km of coastline (Griffiths 2003). The *extreme values* are characteristic of the north-western coast of Great Britain in the vicinity of the Hebrides, where the wave energy density reaches 80 MW/km (Engineering ecology 2003). Wave energy level is shown in Fig. 8.4. On the whole, increased energy density is characteristic of the Pacific coastal zone, which is also extremely long. This index is slightly lower for the Atlantic and Indian Oceans (Modern global changes 2006, vol 2).

There are three basic *methods* for converting wave energy to electricity:

1. *Float* or *buoy systems* that use the rise and fall of ocean swells to drive hydraulic pumps. The object can be mounted to a floating raft or to a device fixed on the ocean floor. A series of anchored buoys rise and fall with the waves. The movement 'strokes' an electric generator and produces electricity, which is then transmitted ashore by underwater power cables.
2. *Oscillating water column devices* in which the in-and-out motions of waves at the shore enter a column and force air to turn a turbine. The column fills with water as the wave rises and empties as it descends. In the process, air inside the column is compressed and heats up, creating energy the way a piston does. That energy is then harnessed and sent to shore by electric cable.
3. '*Tapered channel*', or '*tapchan*', systems rely on a shore-mounted structure to channel and concentrate the waves, driving them into an elevated reservoir. Water flow out of this reservoir is used to generate electricity, using standard hydropower technologies (http://www.oceanenergycouncil.com/index.php/Wave-Energy/Wave-Energy.html).

The world's *first* commercial wave energy plant was put into service in the Portuguese area of Aguçadora on 23 September 2008. Its turbines provide a power of 2.25 MW. It is believed that the number of turbines (generators) in this plant can be increased in the future and that its capacity can be raised to 21 MW (http://en.wikipedia.org/wiki/Wave_farm).

The influence of wave power engineering on the environment is not great and is expressed as *follows* Govorushko (1999): (1) variation in the dynamics of deposit movement within the coastal zone; (2) visual impact; and (3) indirect impact caused by high materials consumption of the wave energy plants.

The effect on *deposit movement dynamics* occurs when the wave energy plants are constructed within the coastal zone. The structures serve as breakwaters, disrupting the balance between erosion and accumulation of deposits. If the energy converters are placed in the deep waters of the open sea, the energy plants do not affect coastal stability (Ageev 2004).

The *visual impact* lies in the fact that, when wave energy plants are installed near a coastline, problems of aesthetic character arise because the plants are visible from shore. The *indirect impact* occurs because significant quantities of metals are melted to construct the wave energy plants, which is ecologically harmful.

In addition, the presence of a continuous line of wave energy plants may become a barrier for *navigation* and prove to be hazardous for ships under stormy

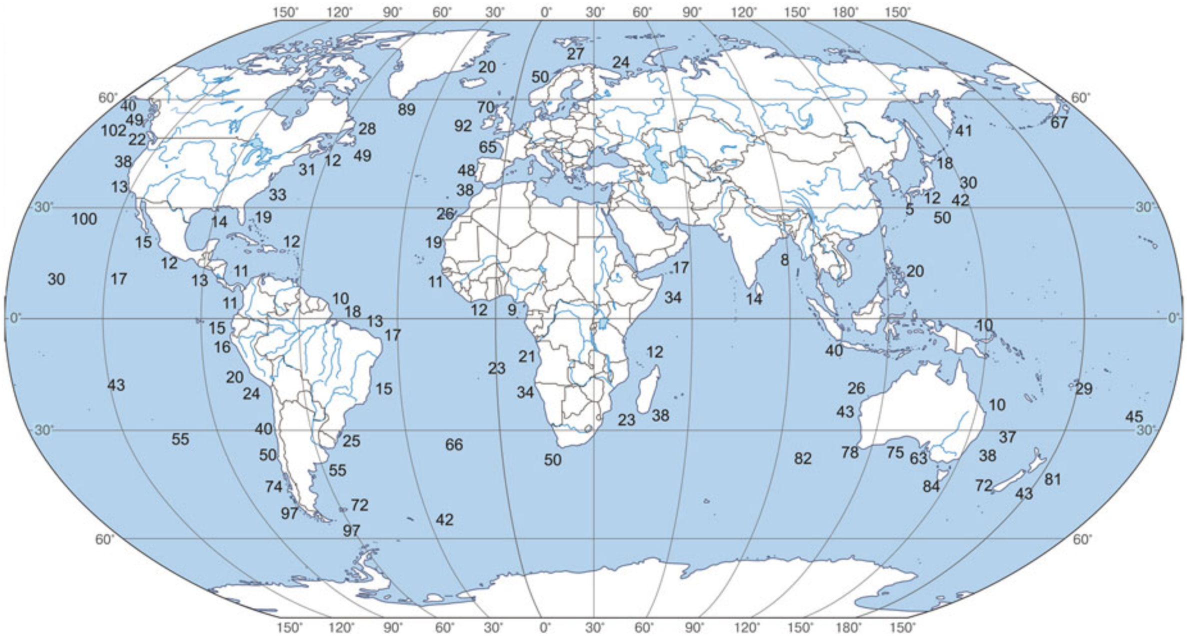

Fig. 8.4 Wave energy level (kilowatts per metre of wave front) (Reproduced with permission of Pelamis Wave Power)

Photo 8.20 The indirect impact of wave farms occurs because, to construct the wave energy plants, significant quantities of metals are melted, which is ecologically harmful. The photo shows sea trials of a Pelamis machine near the estuary of Scotland's River Forth, where it flows into the North Sea. Each Pelamis machine is 140 m long and 3.5 m in diameter and is made up of four sections (Photo credit: Pelamis Wave Power)

conditions. On the whole, wave power engineering is characterized by the least environmental impact of all the energy industries (Govorushko 2003a, b).

The effects of wave power plants on the environment are illustrated by Photo 8.20.

8.4.5 Tidal Power Stations

Tidal power is a form of hydropower that converts the energy of tides into electricity. There are three basic *types* of tidal power plants: (1) tidal stream systems make use of the kinetic energy of moving water to power turbines, in a way that is similar to windmills using moving air; (2) barrages make use of the potential energy in the difference in height between high and low tides; they are essentially dams across the full width of a tidal estuary; (3) dynamic tidal power exploits a combination of potential and kinetic energy: by constructing dams 30–50 km long from the coast straight out into the sea or ocean, without enclosing an area (http://en.wikipedia.org/wiki/Tidal_power).

The SeaGen tidal stream power station built in Strangford Lough (Northern Ireland) in 2007 can serve as an example of power stations of the *first* type. A 1.2 MW underwater tidal electricity generator was installed here. The rates of tidal streams at this location reach 4 m/s (http://en.wikipedia.org/wiki/Strangford_Lough). Such turbines have a minimal effect on the environment.

As for power stations of the *second* type, the tidal water is fed to a baffled-off basin. When the water levels in it and in the sea become equal, the gates at discharge openings are closed. With the onset of ebb tide, the sea water level drops and, at that time, turbines and electric generators connected to them come into action and water leaves the basin gradually (Nekrasov 1990).

Such tidal power plants can be *double-acting*. In this case, turbines work when water moves from the sea to the basin and vice versa. The double-acting tidal power plants are able to generate electric power for periods of 4–5 h with interruptions of 1–2 h four times a day (Marfenin et al. 1995).

The number of power stations using barrage tidal power also is not large. The *La Rance plant*, off the Brittany coast of northern France, was the first and largest tidal barrage plant in the world. It was built in 1966 and has an output capacity of 240 MW. There are also several small power stations. For example, the *Kislaya Guba Tidal Power Station* (Barents Sea, Russia) was built in 1968 and, as of 2009, its output capacity was 1.7 MW (http://en.wikipedia.org/wiki/Kislaya_Guba_Tidal_Power_Station). The *Annapolis Tidal Power Generating Station* (Bay of Fundy, North America) was completed in 1984; its output capacity is 20 MW (http://www.eoearth.org/article/Bay_of_Fundy).

The effects of the tidal power plant at the *Bay of Fundy* were analysed in great detail, which is explained by the *following*: (1) long duration of discussion of its construction suitability (more than 70 years); (2) intense development of environmental legislation in the United States and Canada; (3) economic opportunities in these states; (4) considerable interest of the community in nature conservation; and (5) location of the bay on the border of two states that have responsibilities with regard to the plant (Marfenin et al. 1995).

The *principal* effect of tidal energy stations on the environment is a reduction of *natural water exchange* between the cut-off water body and the sea, which results in the following *consequences*: (1) changes in the distribution of current speeds in the bay; (2) redistribution of bottom sediments; (3) decrease in the aqueous medium stability in the bay (desalination, temperature rise, contamination, etc.) under the action of land processes; (4) decreases in the amplitude of the bay's water level variations; and (5) reductions in water turbidity (Nesvetova and Boytsov 1994; Marfenin et al. 1995).

First of all, a tidal power plant affects hydrobionts because disturbances of exchange of salt and fresh waters, and redistribution of bottom sediments result in changes in the living conditions for sea flora and fauna. The investigations carried out in the La Rance tidal power plant showed an essential change in composition of bottom *hydrobionts,* but they did not record a drop in their numbers (Charlier 2007). At the same time, a sharp reduction in bioproductivity, a twofold decrease in the numbers of species of flora and fauna, and decreases in the total numbers of individuals were observed at Kislaya Guba (Preobrazhensky et al. 2000).

A reduction of water turbidity increases the penetration of sunlight and the productivity of *phytoplankton*. Passage of fish through turbines results in their *loss* due to pressure drop, contact with blades, cavitation, and other causes. Even with the most fish-friendly turbine design, fish mortality per pass is approximately 15%. The loss of large marine *mammals* (whales, seals,

Photo 8.21 Tidal stream generators make use of the kinetic energy of moving water to power turbines, similar to wind turbines that use moving air. This method is gaining in popularity because of the lower cost and lower ecological impact compared to tidal barrages. SeaGen, the world's first commercial tidal generator, in Strangford Lough, Northern Ireland, is shown here. It was installed in April 2008 and was connected to the grid in July 2008. It generates 1.2 MW for between 18 and 20 h a day (Photo credit: http://en.wikipedia.org/wiki/SeaGen, 14 May 2008)

Photo 8.22 The major influencing factor of the effect of tidal hydroelectric stations on the environment is a reduction in the natural water exchange of the cut-off part of water area with the sea. First of all, this influences hydrobionts. The La Rance tidal power plant shown here, off the Brittany coast of northern France, is the first and largest tidal barrage plant in the world. The investigations carried out in the La Rance tidal power plant showed an essential change in composition of bottom hydrobionts (Photo credit: http://en.wikipedia.org/wiki/Rance_tidal_power_plant)

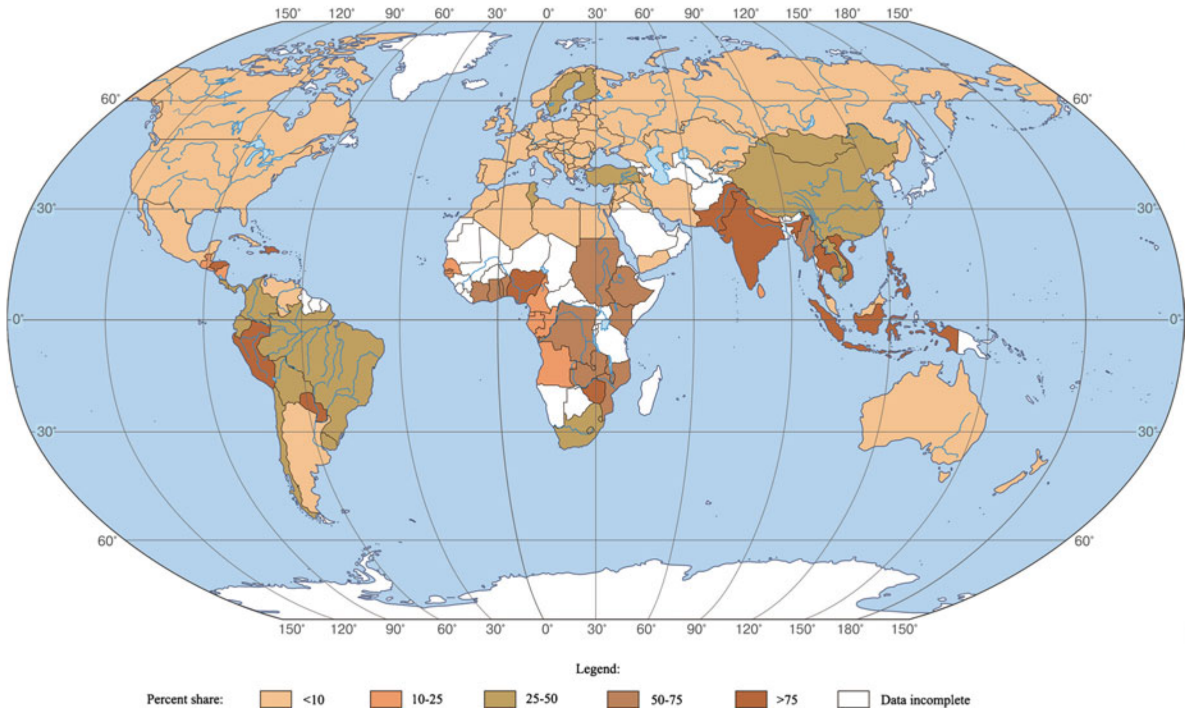

Fig. 8.5 Share of wood fuels in national energy consumption. Wood energy includes fuel wood, charcoal, and black liquor, measured in 1,000 metric tons of oil equivalent (TOE). Wood energy consumption is expressed as a percentage of total final energy consumption from all energy sources in thousand TOE (Reproduced with permission of World Resources Institute)

dolphins, etc.) is possible (http://en.wikipedia.org/wiki/Tidal_power). In addition, the dams not infrequently prevent the renewal of fish resources, since the species that travel to the bays to spawn (salmon, herring, smelt, etc.) can not enter (Preobrazhensky et al. 2000).

The environmental effects of tidal power plants are much less as compared with those of hydropower plants with similar *output capacities*.

The effects of tide power stations on the environment are illustrated by Photos 8.21 and 8.22.

8.4.6 Electricity Production from Biomass

Biomass is organic matter that retains the energy of the Sun owing to the process of photosynthesis. Its initial form is plants. Further along the food chain, biomass can be transferred to herbivorous animals, and then to carnivores when the herbivorous animals are eaten. In turn, humans also eat plants and animals.

The further *transformation of biomass* occurs in many ways. Finally, it can be present in the form of manure, bird droppings, faecal deposits, and domestic waste. Industrial biomass can be grown from numerous types of plants, including miscanthus, switchgrass, hemp, corn, poplar, willow, sorghum, and sugar cane (http://en.wikipedia.org/wiki/Biomass). According to data from different sources, biomass reserves are equivalent to 1.0 (Hall 2002) to 1.2 billion tons of petroleum (Solovyanov 2008)

So far, biomass is mainly used for production of heat energy by three basic *processes*: (1) direct combustion; (2) biomass fermentation; and (3) use of energy carriers produced in the course of biomass transformation (biogas, spirits, etc.) (Engineering ecology 2003).

In the *first* process, biomass is directly used as a fuel. For example, approximately 2.5 billion people in the world use firewood for heating and cooking. Firewood accounts for 15% of the world's energy supply and up to 35% of the supply in the developing countries (Skurlatov et al. 1994). Share of wood fuels in national energy consumption is shown in Fig. 8.5.

In the *second* process, heat released in the course of fermentation by organic waste (manure, droppings,

Photo 8.23 Biomass is organic matter that retains the energy of the Sun owing to the process of photosynthesis. Its initial form is plants, which are used for generation of thermal energy. Firewood and woody coal provide 12% of the world's energy; these materials are used largely in the developing countries. The photo shows a fuel wood and grass fodder market in Darfur, Sudan (Photo credit: United Nations Environment Programme, from UNEP Sudan Post-Conflict Environmental Assessment report, 6 June 2006)

sawdust, etc.) is harnessed. This heat is most often used for heating greenhouses, hotbeds, and other structures. In the *third* process, such energy carriers as biogas and spirits are extracted from biomass. The generation of *electric energy* from biomass is possible with the use of the third process.

Biogas, which is produced by the fermentation of biomass, consists of methane, carbon dioxide, and small amounts of other gases such as hydrogen sulphide. Different organic wastes are suitable for this process, such as the following: waste of fish and slaughtering workshops (blood, fat, guts); wastes of starch and treacle production (fibre and syrup, wastes of potato processing and production of chips – peelings, rinds, rotten tubers); wastes of juice manufacturing (fruit, berry, vegetable marc, grape refuse); waste of milk plants (lactoserum as well as manure); and bird droppings and faeces (http://ru.wikipedia.org/wiki).

Decomposition of biomass occurs under the influence of *three kinds* of bacteria. In the food chain, the subsequent bacteria are supplied with products of the vital functions of the preceding ones. The *first* kind is *hydrolytic*, the *second* is *acid-forming*, and the *third* is *methane-forming* bacteria.

At present, about 60 *technologies* of biogas production are used or are being developed. The most routine method is the anaerobic fermentation in meta-tanks or anaerobic columns (http://www.biogasinfo.ru/about/).

Biogas consists of 55–75% methane and 25–45% carbon dioxide. *Gas yield* depends on the content of dry substance and the kind of raw materials used. One ton of cattle manure may provide 50–65 m^3 of biogas with a methane content of 60%. By using different kinds of plants, one can produce 150–500 m^3 of biogas with methane contents of up to 70%. The maximal quantity of biogas (1,300 m^3), with methane contents of up to 87%, can be obtained from fat.

One kind of biogas is *landfill gas*. It is obtained in the dumps of municipal domestic waste. In 2002, 350 landfill gas production plants in the United States and

Photo 8.24 Further along the food chain, biomass can be transferred to herbivorous animals and transformed into manure. In turn, it can be also used for generation of thermal energy. Dried cow cakes put up for sale as a fuel in Rajasthan State (India) are shown (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 1 November 2007)

Photo 8.25 The generation of electric energy from biomass is possible with the use of biogas and spirits that are extracted from biomass. One kind of biogas is landfill gas. It is obtained in municipal domestic waste dumps. A plant for landfill gas production in Tel Aviv, Israel, is shown. It was rated at processing 150 ton of waste a day (Photo credit: V. Kantor, Greenpeace Russia)

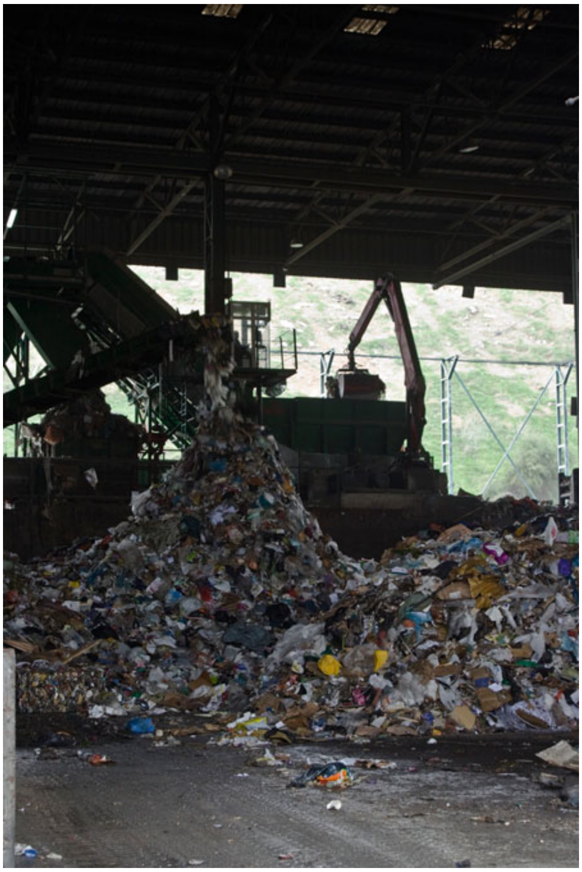

Photo 8.26 Solid municipal wastes as a source of biogas are second in importance to wastes after forestry and agriculture. From 1 cubic metre of biogas, one can obtain from 2 to 3 kWh of electric power. Delivered municipal household wastes in the plant for landfill gas production in Tel Aviv, Israel, are shown (Photo credit: V. Kantor, Greenpeace Russia)

750 plants in Europe were in operation. The total number of such plants in the world is 1,152, and the total energy generated is 3,929 MW, while the amount of waste treated is 4,548 million tons (http://ru.wikipedia.org/wiki).

From 1 m^3 of biogas, one can obtain from 2 to 3 kWh of electric power. There are several *techniques* for generating electric power from biomass through its gasification. For electric power generation, the following equipment can be used: gas turbine units, steam turbine plants, gas-diesel plants, or internal combustion engines with spark ignition (Geletuha and Zheleznaya 1998).

In 2002, 9,733 MW of generating facilities operating on biomass were installed in the United States. Of this amount, 5,886 MW ran on waste of *forestry* and *agriculture*, 3,308 MW were produced from *solid municipal waste,* and 539 MW relied on other sources. In 2003, 4% of the total energy in the United States was generated from biomass. In 2004, a total output of 35,000 MW was produced from biomass.

Power generation from *spirits* is also possible. The spirits are obtained by way of fermentation of sugar-containing and starch-containing products (cereals, potatoes, sugar beets, and sugar cane). For example, the extraction of ethanol from sugar cane bagasse is extensively used in Brazil. Presently, it is economically viable to extract about 288 MJ of electricity from the residues of 1 ton of sugar cane, of which about 180 MJ are used in the plant itself (http://en.wikipedia.org/wiki/Bioenergy).

Power generation from biomass is considered to be the *most environmentally friendly branch* of power engineering, as it contributes to reductions in contamination of the environment with every possible waste (stock raising, domestic activities, forestry, woodworking, etc.).

At the same time, in the course of biomass fermentation for the purpose of ethanol extraction, considerable amounts of by-products (flushing waters and distillation residue) are produced that pollute the environment (Berkovsky and Kozlov 1986). For example, in the extraction of 1 l of ethanol, 13 l of *waste* liquids are produced (Pimentel 2001). In addition, other impacts include *thermal pollution*, depletion of soil organic materials, and exhaustion and *erosion* of the soil (Ageev 2004).

The effects of power generation from biomass on the environment are illustrated by Photos 8.23–8.26.

8.5 Power Transmission and Communication Lines

A *power transmission line* (PTL) is a system of wires (or cables) and auxiliary devices that are designed to transmit electric power from a power station to consumers. A *communication line* is an assembly of engineering devices for transmitting electric signals from the transmitter to the receiver.

According to *location,* power transmission and communication lines can be aerial, underground, or submarine. The longest power line is the Inga-Shaba line (length: 1,700 km). The longest submarine cable is the NorNed cable in the North Sea (length: 580 km).

Photo 8.27 A power transmission line is a system of wires (or cables) and auxiliary devices that are designed to transmit electric power from a power station to consumers. The photo shows a power line from the Luchegorsk thermal electric power station in Primorsky Krai (Photo credit: O. Kabalik, Pacific Geographical Institute, Vladivostok, Russia, 2002)

The longest underground cables are the Murraylink and Riverland/Sunraysia (length: 180 km) cables. Power transmission and communication lines are widely used. The US power transmission grid consists of 300,000 km of lines (http://en.wikipedia.org/wiki/Electric_power_transmission).

The effects of power transmission and communication lines on the environment are observed in the course of construction and operation; as a rule, these effects grow with increases in their lengths and voltages. The influences at the *construction stage* are related to activities such as slashing; laying of access roads; excavation works for setting of poles, towers, and transformer stations; and wiring work. All of these activities are accompanied by noise impacts. During *operation*, impacts are caused by things such as the presence of the ride itself and the power transmission line (towers, wires, transformer stations, and outdoor switchgears), application of physical or mechanical methods of the vegetation destruction within the right of way, and the action of electromagnetic fields.

Power transmission and communication lines affect the following environmental *components*: (1) land resources; (2) vegetation; (3) animal world; (4) atmospheric air; (5) soils; and (6) geomorphology.

The construction of power transmission and communication lines has the strongest effect on *land resources*. An area with a radius of 2 m around towers is allotted for use by a PTL on a permanent basis. For a PTL with different voltages, it is 700–4,500 m^2/km (Lyalik and Reznikovsky 1995). As for the remaining part of the territory, constraints are imposed on possible use of land for other purposes. From 7.5 to 18 ha of alienable lands fall within 1 km of the length of a 500 kV transmission line (Babayev et al. 1984). This situation affects *agriculture* to the greatest extent. The disordered arrangement of power transmission and telephone lines breaks the integrity of fields and natural meadows. Problems arise in using farming equipment, and towers and poles prevent aerial activities.

The effect on *vegetation* consists of its large-scale destruction. For example, the length of the rides for the power transmission and communication lines in the former USSR increased every year by 20,000 km and, in this case, 30,000 ha of forests were cut down (Humans and the environment 1988). Later on, in the course of operation, repeated cuttings are regularly carried out and herbicides are applied for maintenance of rides.

An increase in the ride width when small sections of forest are crossed by lines (first of all, under conditions of forest-tundra and forest-steppe), results not infrequently in disappearance of the whole forested area due to *water imbalance* and dying-off of woody vegetation on the edge of the ride as a result of *windfalls* (Popov 1986).

The effects on the *animal world* are ambiguous and are caused by different factors. For example, the *presence of a ride,* on the one hand, results in the '*forest border effect*', increases in the diversity of the living environment and fast growth of the number of bird and animal species. On the other hand, a ride can be an insurmountable obstacle for movement of animals. To a considerable degree, the tendency of the impacts (positive or negative) depends on the ride width. According to data from different sources, positive effects are noted at widths of 10–100 m, while negative effects are noted at widths of 60–200 m and more (Humans and the environment 1988; Environmental problems 1989; Lyalik and Reznikovsky 1995; and others).

Effects on *birds* are also caused by the *presence of the PTLs* and transmission of *electric energy* by wire. In 53% of cases birds of even the same species fly over the wires, in 7% of cases they fly under them, and in 40% of cases they fly between wires; that is, within the most hazardous zone. The major cause of deaths of birds is traumas caused by collisions with towers and wires. The numbers of birds killed as a result of collisions with PTL towers and wires depend strongly on the locality: in the field biotopes, eight birds are killed a year per kilometre, while where PTLs pass through the narrow bridge between the sea and another water body, the number of birds killed can reach 70,000 individuals a year per kilometre of the PTL (Ivanov and Sedunova 1993). In all biotopes, the numbers of birds killed increase sharply during the autumn and spring migrations, especially if the PTLs cross the flight path.

Birds are rarely killed by *electric shock*. Generally, when such deaths do occur, they happen with large birds due to wire closure by opened wings, and more often in rain or snowstorms (Ivanov and Sedunova 1993). In France, the hollow poles of telephone lines are mortal traps for animals living in holes. Such animals (e.g. owls, bats, squirrels, and small birds), penetrate through holes into the interior of the poles, and they can not escape them and thus die from lack of food. In France, there are millions of such poles, and inspection showed that some of them were filled with the bodies of such animals to heights of 2 m (Noblet 2004).

The effects on *ichthyofauna* are mainly related to electric power transmission. For example, if electric and magnetic field strengths exceed permissible values in functioning submarine cables, a zone of stable frightening effect to fish is created (so the cable becomes an obstacle for the migration of fish), or immobilization reactions resulting in paralysis of muscles and breathing appear (Kadomskaya et al. 2006).

Air pollution occurs when electric energy is transmitted by wire (gas flows in the course of corona discharges). It is believed that ozone formed in the operation of PTLs contributes to the destruction of forests (Environment 1999, vol 1).

Soil contamination occurs during the laying of underground lead-sheathed communication cables. In Denmark, for example, lead from cable sheaths was found to accumulate in soil and reach concentrations of 85 mg/kg (Jaspers et al. 2001).

Photo 8.28 An area with a radius of 2 m around towers is allotted for use by a power transmission line on a permanent basis. This situation affects agriculture to the greatest extent. The disordered arrangement of power transmission and telephone lines breaks the integrity of fields and natural meadows. Problems arise in using farming equipment, and towers and poles prevent aerial activities. A PTL crossing agricultural lands in England is shown (Photo credit: Ilan Kelman (http://www.ilankelman.org))

Photo 8.29 Effects on birds are also caused by the presence of the power transmission line and transmission of electric energy by wire. The major cause of deaths of birds is trauma caused by collisions with towers and wires. In all biotopes, the numbers of birds killed increase sharply during the autumn and spring migrations, especially if the PTLs cross the flight path. The photo shows a dead mute swan after a collision with power lines (Photo credit: D. Urquhart, Essex County Council, United Kingdom)

Photo 8.30 The effects of power lines on ichthyofauna are mainly related to electric power transmission. If a PTL crosses a river, it creates an electromagnetic dam that can be an obstacle to the migration of fish. The photo shows a power transmission line crossing the Bikin River in Primorsky Krai, Russia (Photo credit: V. Korobov, Pacific Geographical Institute, Vladivostok, Russia, July 2010)

Power transmission and communication lines make a considerable contribution to changes in the *geomorphologic environment*. For the construction of 1 km of PTL, about 100 m^3 of ground are extracted. One kilometre of aerial communication line requires the extraction of 16 m^3 of ground, while for laying 1 km of communication cable, 250–300 m^3 of ground are extracted (Khazanov 1975).

The effects of power transmission and communication lines on natural components are illustrated by Photos 8.27–8.30.

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9 Industry

Abstract

In an extended sense, the term *industry* means the totality of enterprises occupied with the production of instruments of labour, extraction of raw materials and minerals, and power generation. It also includes the further processing of products manufactured in industry or in other activities (agriculture and forestry, and fishing). Electric power generation and transmission were considered earlier in Chap. 8, while extraction of raw and other materials is described in Chap. 10. The branches considered here belong to the manufacturing industry. They include the enterprises occupied with processing raw and other materials. The characteristic features of these industrial enterprises are serial production, division of labour, and the use of highly productive machines and equipment and their maximum specialization. Different industrial branches differ strongly in their ages. Among the oldest are the textile industry and metallurgy, while among the relatively young ones are the pulp-and-paper and chemical industries. On the whole, industry is the economic sector having the most important effects on the development of other kinds of human activity.

Keywords

Industry • Manufacturing • Accidents • Condemnation of land • Economic loss • Environmental impacts • Influencing factors • Natural components • Technological processes

During industrial production, raw materials are transformed into finished goods on a large scale. Such finished goods may be used for manufacturing other, more complex products, such as aircraft, household appliances, or automobiles, or sold to wholesalers. Industrial regions of the world are shown in Fig. 9.1.

9.1 Chemical Industry

In the enterprises of the *chemical industry*, raw materials of oil and mineral origin are used to produce chemical intermediates or finished products through chemical reactions (Protection of the atmosphere against industrial

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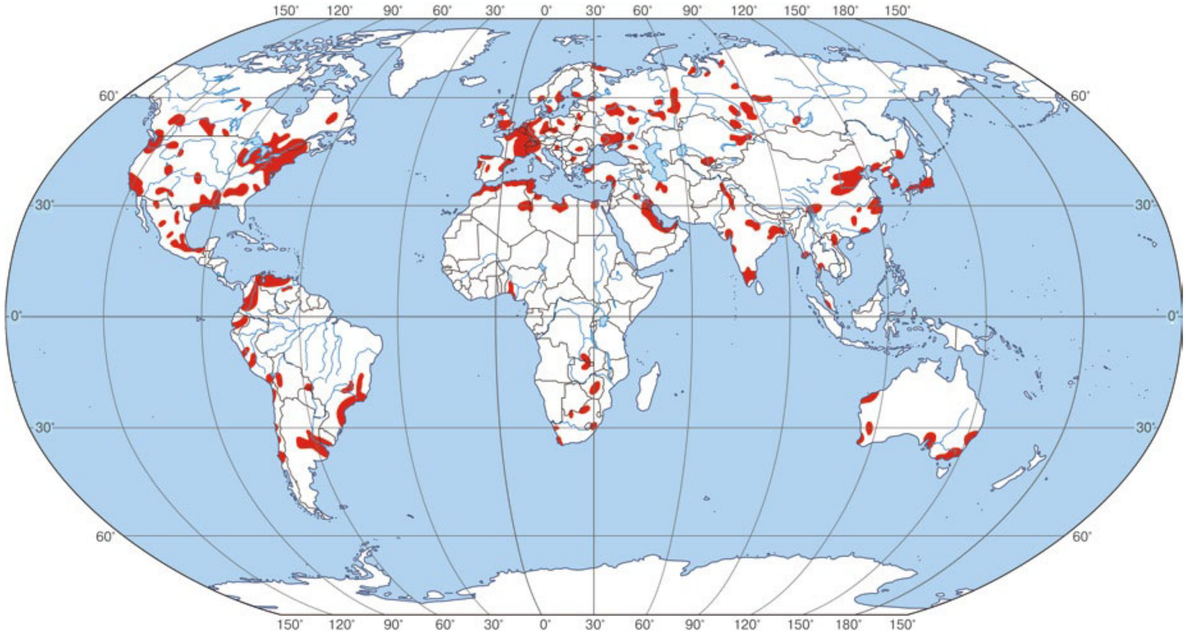

Fig. 9.1 Industrial regions of the world (Maksakovsky 2006, vol I. Reproduced with permission of V.P. Maksakovsky)

pollution 1988, vol 1). The *major products* of this branch are fertilizers, oil products, solvents, acids, bases, and chemical intermediates.

The *complexity* of the chemical industry is confirmed by the fact that 500 industrial chemical substances are produced as a result of 400 processes, using 1 of 10 kinds of charge stock: benzene, butylene, cresol, ethylene, methane, naphthalene, paraffin, propylene, toluene, and xylene.

These organic intermediates, together with 100 inorganic acids, salts, and bases manufactured by the chemical industry, are used to produce more than 70,000 kinds of products (synthetic fibres, plastics, pesticides, dyes, pigments, pharmaceutical products, etc.). Together with the by-products, 500,000–600,000 synthetic compounds are produced (Protection of the atmosphere against industrial pollution 1988, vol 1). This industrial sector is *most developed* in the United States, Japan, Germany, Great Britain, France, and Italy (Maksakovsky 2006, vol 1).

The impacts of this industry on the natural environment are *extremely diverse*, which is explained by the enormous number of technological processes and manufacturing operations, composition of raw materials, physico-geographical features of affected regions, and so on.

The major *reasons* for the atmospheric pollution released by chemical enterprises are the *following* (Drugov et al. 1984): (1) incomplete product yield (losses of finished product, incomplete reaction execution, etc.); (2) discharge of admixtures and pollutants in the processing of raw materials (e.g. fluorides from natural phosphates and ores, and sulphur dioxide and hydrogen sulphide from natural gas); (3) losses of substances used for manufacturing processes (e.g. nitrogen oxides in the production of sulphuric acid); and (4) emission of odorous substances and oxidation and destruction products (in processes such as the synthesis and reprocessing of polymer materials, and production of solvents) into the air.

The most *significant gaseous pollutants* of the atmosphere with regard to the volume of their production and toxicity are (Bretschneider and Kurfurst 1989) (1) chlorine; (2) nitrogen oxides; (3) sulphur dioxide and sulphur trioxide; (4) hydrogen chloride (hydrochloric acid); (5) hydrosulphide; (6) hydrogen fluoride; (7) carbon disulphide; and (8) fluorine and its compounds.

The chemical industry is a powerful source of effects on *surface waters*. The considerable withdrawal of water that is used in the manufacturing processes for purposes such as cooling and flushing is characteristic of this branch. During the manufacturing of chemical substances, pollution of water with chemicals and by-products takes place.

Some of the *factors* causing hydrospheric pollution are rainfall run-off from territories where industrial structures, storage plants, and storage of raw materials and finished products are located; and discharges of bleed waters from cooling systems, flushing waters, and manufactured product (Environmental assessment sourcebook 1992). *Typical pollutants* of surface waters include phenols, spirits, resins, chlorides, sulphates, sodium, and calcium (Arzhanov 1994).

In chemical production, more than 800 types of solid *waste* are formed and only one-third of them is fully or partially used (Arzhanov 1994). The solid wastes include residues of raw materials and polymers, and sludge and sediments formed in treatment facilities and feed systems of steam-generating units as well as in the course of washing tanks and reservoirs. Considerable ash-and-slag waste is also formed as a result of the operation of coal-dust steam-generating units. Depending on concrete conditions, the solid waste contains various pollutants, such as chemical and radioactive substances, pathogenic microorganisms, and viruses (Chizhov and Shekhovtsov 2004).

Considerable *noise* is also characteristic of many chemical enterprises, and sources include *such production equipment* as compressors, gas turbines, pumps, control valves, furnaces, flares, heat exchangers with air cooling, evaporative cooling towers, and ventilation systems (Environmental assessment sourcebook 1992).

It also should be noted that many materials and substances involved in the production of chemicals are *dangerously explosive* and constitute *fire hazards*. Taking into account the fact that the application of high pressure as well as the use of substances with high reactivity are characteristic of manufacturing technologies, they result in serious danger of explosions and drastic consequences.

9.1.1 Petrochemical Industry

The *petrochemical industry* is a part of the chemical complex based on the products of the oil, gas condensate, and associated petroleum and natural gas processing.

The raw materials and manufacturable products of this industry can be divided into four *groups*: (1) raw materials (two kinds: oil and gas); (2) base intermediate products (about 10 kinds; e.g. ethylene, propylene, benzene, and methanol); (3) petrochemicals (about 100 kinds: spirits, glycols, oxides, anhydrides, and others); and (4) final petrochemical products (about 1,000 kinds, such as plastics, resins, synthetic fibres, synthetic rubbers, synthetic detergents, and varnishes). In transitions from one group to the other, the number of products increases by an order of magnitude (Braginsky 2009).

The petrochemical industry involves more than 100 *technological processes*. *Major processes* include rectification, cracking, reforming, alkylation, isomerization, carbonization, pyrolysis, dehydrogenation (including oxidizing processes), hydrogenation, hydration, ammonolysis, oxidation, and nitration (Ratanova 1999).

The petrochemical industry arose in the 1930s when the manufacturability of alkenes from associated gases was proved. Before that time, *coal* was the major raw material used in the chemical industry (Marshall 1989). In the petrochemical industry, 6.5% of the oil produced and 5–7% of the natural gas are used. In 2007, total proceeds from sales of petrochemical products in the world reached US$2.85 trillion (Braginsky 2009).

Among the *countries leading* in volumes of oil and gas processing are the United States and countries of Western Europe (particularly Italy, Germany, France, and Great Britain). This industry is developing at a swift rate in China (Braginsky and Shlikhter 2002).

There are essential *differences* in the types of *raw materials* used in different countries. In the United States, Canada, Mexico, Saudi Arabia, a number of Asiatic countries, Brazil, and Venezuela, the major kinds of raw materials are products of *gas processing* plants (ethane, propane, butane, etc.), while in European countries, Russia, China, India, Japan, and Korea, fractions from *oil processing* are used as raw materials (Braginsky 2009).

The petrochemical industry affects, first of all, the following natural *components*: (1) atmospheric air, (2) surface waters, and (3) withdrawal of lands. The effects on other components are indirect. It also affects public health and results in considerable mortality and trauma.

The *most significant pollutants* of the atmosphere (*in the order of decreasing priority*) are hydrogen sulphide,

Photo 9.1 The petrochemical industry delivers about one billion tons of different aerosols into the atmosphere per year, making a considerable contribution to global warming. The most significant pollutants of the atmosphere are hydrogen sulphide, sulphur dioxide, phenol, hydrocarbons, nitrogen oxides, carbon oxides, and dust. The photo shows emissions at the Shell Puget Sound Refinery, Anacortes, Washington (Photo credit: Walter Siegmund)

sulphur dioxide, phenol, carbohydrates, nitrogen oxides, carbon oxides, and dust (Karlovich 2005). The petrochemical industry delivers into the atmosphere about one billion tons of different aerosols per year (Vladimirov and Izmalkov 2000), making a considerable contribution to global warming (Gielen and Yagita 2002).

In many cases, the pollutants are not released into the air in great volumes, but they are characterized by high toxicity (Chizhov and Shekhovtsov 2004). Depending on the technological process, the composition of discharges changes markedly. For example, *catalytic cracking* releases sulphur and nitrogen oxides, carbohydrates, aldehydes, and ammonia into the atmosphere. In the course of *desulphurization*, hydrogen sulphide and mercaptans are released, while in the case of *catalytic hydrocracking,* carbon monoxide, ammonia, and hydrogen sulphide are released (Ratanova 1999).

The major *sources* of pollution are plants for sulphur extraction and catalytic crackers (Khaidarov et al. 2005). Depending on the peculiarities of oil composition, air pollution with different substances is possible. For example, cases are known when oil processing resulted in severe air pollution with mercury (Mark 2001).

Gas processing also makes its contribution to atmospheric pollution. In the operation of one of the gas processing plants in western Siberia (Russia), 230,000 ton of pollutants are released into the atmosphere every year (Geoecology of the North 1992). On

Photo 9.2 The combustion of petroleum gas results in a situation in which, within a radius of 200–250 m of a flare, the vegetation is fully destroyed, while within 3 km of it, trees suffer and cast leaves. Trees and bushes suffer from necroses, while twisted needles and shorter sprouts are characteristic of conifers. Gas flaring in west Siberia, Russia, is shown (Photo credit: I. Gavrilov)

the whole, the petrochemical industry is the greatest consumer of atmospheric oxygen among all industries (Opalovsky 1990).

The effects on *surface waters* are caused by the withdrawal of great volumes of water that is needed for participation in the chemical reactions, cooling, process steam generation, and washout of foreign substances from oil products (Environmental assessment sourcebook 1992). Per 1 ton of refined oil, 2.0–3.5 m^3 of water are used (Vladimirov and Izmalkov 2000).

Considerable quantities of oil products, sulphates, chlorides, nitrogen compounds, phenols, and salts of heavy metals enter surface waters with the waste waters of refineries (the annual quantity is 500 m^3) (Ratanova 1999).

In 2002, for example, the petrochemical *enterprises of Russia* discharged to surface water bodies the *following*: 1,175,000 ton of chlorides; 188,000 ton of sulphates; 19,000 ton of suspended matter; 14,000 ton of nitrates; 7,100 ton of magnesium; 4,400 ton of ammonium nitrogen; 766 ton of fluorine; 424 ton of boron; 384 ton of carbamide; 244 ton of nitrites; 172 ton of sodium; 141 ton of mercury; 107 ton of calcium; and 90 ton of formaldehyde (Chizhov and Shekhovtsov 2004).

The wastes discharged, besides polluting water bodies, also result in variations in such factors as pH and biochemical consumption of oxygen (Adeyinka and Rim-Rukeh 1999). These changes, in turn, affect *hydrobionts*. The withdrawal of *lands* occurs in the construction of petrochemical enterprises and in storage of the waste products. Every year, the petrochemical industry generates three billion tons of *solid waste* (Vladimirov and Izmalkov 2000).

The atmospheric pollution has indirect effects on *soils* and *vegetation*. In the case of subsoil oil pollution, destruction of grass cover, change in its species composition, and depression of woody vegetation are observed. The combustion of *petroleum gas* results in a situation in which, within a radius of 200–250 m of

Photo 9.3 Every year, about 1,500 accidents and catastrophes occur in the petrochemical industry, and 4% of them are accompanied by the death of 100–150 people and property damage of up to US$100 million. Fire fighters battling an oil tank fire at a Union Oil refinery in Wilmington, California (United States), in 1951, are shown (Photo credit: http://en.wikipedia.org/wiki/Oil_refinery)

a flare, the vegetation is fully destroyed, while within 3 km of it, trees suffer and cast leaves. Trees and bushes suffer from necroses, while twisted needles and shorter sprouts are characteristic of conifers (Shuitsev 1982).

This kind of economic activity influences the life and health of *people*. In the petrochemical industry, explosive mixtures arise during technological processes. More frequently, they are generated by escaping gases, vapours, or fogs. For example, an explosion happened on 25 December 1997 in one of the installations of a petrochemical plant in East Malaysia (Ahmadun et al. 2003).

The first severe *fire* caused by leakage of liquefied natural *gas* took place on 20 October 1944 in the city of Cleveland, Ohio (United States), and killed 130 people. The first major incident related to liquefied *petroleum gas* occurred on 28 July 1959 in the state of Georgia (United States), and resulted in the loss of 23 lives (Marshall 1989). Every year, about 1,500 accidents and catastrophes occur in the petrochemical industry, and 4% of them are accompanied by the death of 100–150 people and property damage of up to US$100 million (Safety of ability to live 1995).

The effects of the petrochemical industry on the environment are illustrated by Photos 9.1–9.3.

9.1.2 Mining and Chemical Industry

The *mining and chemical industry* is a complex of enterprises engaged in production, concentration, and pre-processing of apatite and phosphatic rocks, natural potassium salts, and ores containing sulphur, boron, arsenic, barium, and barite, as well as iodine and bromine.

The basic product of this industry is *fertilizers*, which are subdivided into phosphoric, potash, and nitrogenous fertilizers. There are also *compound* mineral fertilizers, which contain two or three nutritive substances. Strictly speaking, the manufacturing of nitrogenous fertilizer does not belong to the mining and chemical industry, but we will consider it here for the sake of convenience.

Photo 9.4 A combination of two natural factors – high water mineralization and an excess of solar energy – is characteristic of the Dead Sea area. Each kilogram of water contains 190 g of magnesium chlorides ($MgCl_2$) and calcium chlorides ($CaCl_2$), 67 g of sodium chloride (NaCl), 12.7 g of potash chloride, and many other salts. The average annual amount of solar radiation approaches 200 kcal/cm^2. The photo is an orbital image of Jordanian and Israeli mineral evaporation ponds at the south end of the Dead Sea, separated by a central dike that runs roughly north-south along the international border (Photo credit: Russian Space Agency)

The prevalent *phosphoric fertilizers* are superphosphate, double superphosphate, ammophos, precipitate, and ground phosphate rock. Phosphorites (sedimentary rocks containing phosphoric anhydride, P_2O_5) and apatite (mineral, calcium phosphate) serve as raw materials for their production.

In the mining of *phosphoric ores* in the world, the phosphorites predominate over apatite ores (91% versus 9%). The sole exception is in Russia, where the inverse ratio is observed: The ratio for ore reserves is 18–82%, while that for production output is 5–95%. The *leading nations in the extraction* of phosphatic rocks are (1) China, (2) the United States, (3) Morocco, (4) Brazil, (5) Russia, (6) Jordan, and (7) Tunisia. These countries account for 85% of global production (Lomakin 2007).

The *techniques* for manufacturing different kinds of fertilizers differ from each other. Ground phosphate rock is manufactured by crushing natural phosphorite; it is dried and ground. Superphosphate is produced by the decomposition of natural phosphorite by sulphuric acid, and the precipitate is produced by the neutralization of phosphoric acid with milk of lime (Parfenov 1990).

Potash fertilizers (potassium chloride, potassium sulphate, and double manure salt) are produced from natural salts, primarily carnallite and sylvinite. The world reserves of potassium salts are about 50 billion tons. More than 80% of reserves of ore used for potassium production falls in just three countries: Canada, Russia, and Belarus. The *major countries* producing potassium ores are Canada, France, Germany, the United States, Belarus, and Russia. The production of potash fertilizers includes the separation of calcium chloride from associated salts by methods of selective solution or flotation (Ratanova 1999).

The raw feedstock for production of *nitrogen fertilizers* (ammonium nitrate, carbamide, ammonium sulphate, etc.) is ammonia. Earlier, ammonia was produced from coke and coke oven gas, while now it is produced from natural gas. The *leaders* in ammonia production are China, the United States, India, and Russia. Nitrogen fertilizers account for more than half of fertilizer production (85 million tons), while phosphate and potash fertilizers account for 35 million tons and about 25 million tons, respectively (Maksakovsky 2006, vol 1).

Photo 9.5 The basis of the production process shown in Photo 9.4 is formed by differences in the solubility of natural salts depending on concentrations of brines. Water from the Dead Sea is delivered to ponds. As it evaporates, one or another salt precipitates. The retained water is drained off to the neighbouring pond evaporator, where there is crystallization of other salts by further evaporation. The precipitated salt, along with the bottom brine, is transferred by means of specialized dredgers through a floating pipeline to shore for further processing and refining. The photo shows a dredger on the Dead Sea (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 18 July 2010)

The mining and chemical industry has effects on the following natural *components*: (1) atmospheric air, (2) surface waters, (3) soils, (4) animal world, and (5) vegetation.

The composition of *atmospheric* emissions depends strongly on the charge stock and technique of operation. In the production of phosphate fertilizers, the major pollutants are fluorides, which are present in gaseous and aerosol emissions. In addition, the air is polluted with arsenic, copper, zinc, strontium, thorium, and rare earth elements (Gorbunov et al. 2001). Every day, the plants manufacturing nitrogen fertilizers emit 5–12 ton of nitric oxides and nitric acid (Chapkavichene et al. 1987), as well as ammonia and formaldehyde.

The effects on *surface waters* are related to increased content in waste waters of sulphates, phosphates, fluorine, copper, and zinc (Gorbunov et al. 2001). The influences on *soils* are caused by storage of waste. For example, in the production of potash fertilizers, the stocking of halite waste results in considerable salinization of soils (Baboshko 2005). Dust particles in high concentrations are able to considerably decrease soils' permeability to water (Environmental considerations during potash production 1987).

The effects on *vegetation* and the *animal world* are indirect and related to contamination of water and air. In Qatar, for example, the production of fertilizers results in the discharge of about three million tons of ammonia and five million tons of urea every

Photo 9.6 Pollution of the atmosphere from oil shale processing and chemical plants arises from several sources. These include carbon dioxide released by the decomposition of kerogen and carbonate minerals in the extraction process – which also releases some methane – the generation of the energy needed to heat the shale and in the other oil and gas processing operations, and the mining of the rock and the disposal of waste. The photo shows the Kiviõli Oil Shale Processing & Chemicals Plant in Ida-Virumaa, Estonia(Photocredit: http://en.wikipedia.org/wiki/Environmental_impact_of_the_oil_shale_industry, 11 August 2007)

year to the Persian Gulf in the form of liquid wastes, which have extremely unfavourable effects on hydrobionts (Abdel-Moati and Al-Ansari 2000). The volley of industrial sewage of the Stebnikovsky plant for production of potash fertilizer (Ukraine) in September 1983 gave rise to total disappearance of hydrobionts in the upper Dniester River (Cheredarik and Shnarevich 1988).

The mining and chemical industry belongs to industries with high risks of *casualties*. The production of fertilizers involves high risks of explosions. For example, on 21 September 1921, about 4,000 ton of ammonium nitrate exploded in the town of *Oppau* (Germany), killing more than 500 people (Marshall 1989). About 80% of the buildings in the town were destroyed (http://en.wikipedia.org/wiki/Oppau_explosion). After 80 years, on 21 September 2001, a similar incident was recorded in a plant producing fertilizers in the town of *Toulouse* (south-western France); 32 people were killed and more than 2,400 people were wounded (Mapping the impacts of recent natural disasters 2005).

The effects of the mining and chemical industry on the environment are illustrated by Photos 9.4–9.6.

9.1.3 Other Chemical Industries

There are several important industries in addition to the petrochemical and mining and chemical industries. These include the resin and chemical and pharmaceutical industries and the manufacture of acids.

The *resin industry* is developed to the *greatest extent* in the United States, Canada, Sweden, and Finland. It is based on chemical processing of forest raw materials (timber, bark, needles, dip, etc.), through the use of various technologies.

For example, the *wood charcoal* used in the medical industry is produced through the chemical processing (dry distillation) of birch wood. The dry distillation of birch bark (sometimes, asp bark) is necessary for the production of *tar* used in the tanning and medical industries. Small fir branches with needles are raw material for the manufacture of *fir needle oil*. Dip (resin of Korean pine, other varieties of pine, fir, and larch) is used to manufacture *colophony* and *turpentine* (Shelgunov et al. 1989).

The *chemical and pharmaceutical industry* is engaged in the production of pharmaceutical products. It includes the enterprises involved in manufacturing synthetic and phytochemical preparations, antibiotics, vitamins, blood substitutes and organic preparations, and different types of medicaments (such as injection in ampoules, tablets, dragée, capsules, pills, suppositories, liniments, emulsions, aerosols, and plasters).

In the industrial production of chemical and pharmaceutical preparations, different raw materials obtained from plant and animal products as well as products extracted by way of chemical synthesis are widely used. The chemical raw materials are the most commonly encountered.

The following *kinds* of *manufacturing operations* are *used*: (1) prior operation (transformation of materials: milling of hard raw materials, separation of solid substances, and removal of liquids and gases from them with the use of settling, filtration, centrifugation, cooling, crystallization, vacuum processes, etc.); (2) manufacture of medicinal preparations (sulphurization, nitration, halogenation, amination, reduction, oxidation, and other reactions are used); and (3) final (drying, crushing, pelletizing, production of ampoules, pre-packaging, and packing).

The major products in the *manufacture of acids* are sulphuric and nitric acids. In the past, the use of sulphuric acid was so widespread that its production was considered for a long time to be an indicator of the overall level of development of the chemical industry (Marshall 1989).

Sulphur, sulphides of metals, hydrogen sulphide, waste gases of thermal power plants, and sulphates of iron, calcium, etc. serve as raw materials for the production of *sulphuric acid*. The basic *stages* of its manufacture are: (1) burning of raw materials with the production of sulphur dioxide, (2) oxidation of sulphur dioxide into sulphur trioxide, and (3) absorption of sulphur trioxide. The *top ten countries* in the production of sulphuric acid are the United States, Japan, Canada, France, Germany, Spain, Russia, Ukraine, China, and Brazil (Maksakovsky 2006, vol 1).

Sulphuric acid is used for the following *purposes*: (1) in the production of mineral fertilizers; (2) as an electrolyte in lead-acid batteries; (3) for the manufacture of different mineral acids and salts; (4) in the production of artificial fibres, colouring agents, smoke-forming substances, and explosive materials; (5) in the petroleum, metalworking, textile, tanning, and other industries; and (6) in reactions of industrial organic synthesis: (a) dehydration (production of diethyl ether and esters); (b) hydration (ethanol from ethylene); (c) sulphurization (synthetic cleaning agents and intermediate products in the manufacture of colouring agents); and (d) alkylation (manufacture of isooctane, polyethylene glycol, and caprolactam) (Rodionov and Van Kui 2003).

Nitric acid ranks next to sulphuric acid in production volume. The raw material used in its production is ammonia. This acid is *used* in the production of mineral fertilizers; in the military industry; in the publishing business (etching of printing forms); and for other purposes.

The above-mentioned industries influence the following natural *components*: (1) atmospheric air, (2) surface waters, (3) underground waters, and (4) vegetation.

The effects on *atmospheric air* are expressed as contamination with dust and gases. In the chemical and pharmaceutical industry, *dust* is formed mainly in the course of crushing and milling of feedstock. Crushing is carried out in jaw, roll, cone, hammer, and other crushers. Milling is performed using ball and porcelain mills and disintegrators.

In the production of acids, gases predominate in the atmospheric emissions. For example, in the course of *sulphuric acid* manufacture, the basic components of atmospheric emissions are nitrogen oxide, nitrogen dioxide, and sulphur dioxide. In the case of *nitric acid*

Photo 9.7 The effects of chemical enterprises on surface waters result from the discharge of sewage. These waste waters usually are characterized by a large variety of materials. The photo shows effluents of a chemical plant in Iowa (United States) (Photo credit: U.S. National Oceanic and Atmospheric Administration)

Photo 9.8 Wood charcoal used in the medical industry is produced through the chemical processing of birch wood. At a sub-industrial level, it is one of the primary causes of deforestation in the developing world. Charcoal production is usually illegal and nearly always unregulated. The photo shows a charcoal factory in Bodenfelde, Germany (Photo credit: Heinz-Josef Lücking, 13 July 2009)

manufacture, nitrogen oxide and ammonia are emitted; in the manufacture of *hydrochloric acid*, chlorine is emitted; and in the manufacture of *phosphoric acid*, anhydrous hydrogen fluoride is emitted (Stadnitsky and Rodionov 1996).

As a result of production of 1 kg of *sulphuric acid* in the Federal Republic of Germany, discharges of sulphur dioxide reach 2.6 kg, which corresponds to total sulphur dioxide emissions of 8,000 ton/year in that country (Environment 1999, vol 2). The basic components of discharges of *wood-chemical* enterprises are oxides of nitrogen, sulphur, and carbon; and sulphurous anhydride (Bobkova et al. 1999). For plants producing *soda*, emissions of ammonia, phosphoric anhydride, sulphur trioxide, and nitrogen oxides are characteristic (Protection of the atmosphere against industrial pollution 1988, vol 1).

Effects on *surface waters* result from the discharge of sewage. The production of 1 ton of sulphuric acid results in the formation of 45–70 m^3 of sewage (Goldberg 1987). In the production of pigment (*titanium dioxide*), waste waters containing large quantities of sulphuric acid are discharged (Environment 1999, vol 2). The waste waters of *pharmaceutical enterprises* are characterized by a large variety of materials. These include alkalis, different organic substances, and components of the product manufactured. For example, in the production of antibiotics, spent

Photo 9.9 Production of different chemicals is dangerous for employees. The photo shows a chemical burn caused by exposure to a <10% (by weight) sodium hydroxide solution (lye). The photo was taken 44 h after exposure (Photo credit: http://en.wikipedia.org/wiki/Sodium_hydroxide, 13 May 2009)

solutions are characterized by very high contents of organic matter (biochemical oxygen demand [BOD] is 4,000–8,000 mg/l), mineral and organic salts, carbohydrates, and acids; wash waters are polluted with acids, alkalis, and acetone (Goldberg 1987).

The influences on *underground waters* are often related to waste storage. For example, the sludge collectors of factories manufacturing *soda* occupy territories of 3–4 ha. In case of damage to the hydraulic seals of collectors' foundations, polluted waters filter to the underground horizons (Ratanova 1999).

The effects on *vegetation* result mainly from atmospheric pollution. For example, a depression of forests is caused by emissions of a wood-chemical complex in the north of European Russia: the lifetime of needles is reduced (particularly for pines), and there is deterioration and dieback of forest species (Bobkova et al. 1999).

The effects of these chemical industries on the environment are illustrated by Photos 9.7–9.9.

9.2 Metallurgy

Metallurgy is a branch of industry that covers the processes of producing metals from ores or other materials. In metallurgical works, the following *procedures* take place: (1) ore treatment with a view toward preparing it for the extraction of metals (crushing, ore dressing, clotting, etc.); (2) extraction (recovery) of metals from ores and other materials; (3) purification of metals to free them of undesirable impurities (refinement); and (4) production of metals and alloys (Polytechnic dictionary 1989).

In accordance with major operating procedures, metallurgy is subdivided into *pyrometallurgy* (producing metals and alloys under conditions of high temperatures; i.e. fusing) and *hydrometallurgy* (low-temperature processes of metal extraction in chemical solutions).

Pyrometallurgy is the basic and most ancient area of metallurgy. Since olden times to the end of the nineteenth century, the production of metals was exclusively based on pyrometallurgic processes. At the turn of the twentieth century, the other great branch of metallurgy – *hydrometallurgy* – gained industrial importance. However, pyrometallurgy maintains the dominant position in the scale of operation and in variety of processes (Ratanova 1999).

Early in the twentieth century, alongside with flame methods of heating, different kinds of *electric heating* (arc, induction, etc.) began to be used in metallurgy; at the same time, *electrolysis* of molten chemical compounds (production of aluminium and other non-ferrous metals) was introduced in the industry.

During the last half of the twentieth century, plasma melting of metals, zone melting, and electric fuel-fired smelting became widespread. The metallurgical processes based on the use of electric current are identified as an independent field of pyrometallurgy: electrometallurgy.

9.2.1 Iron and Steel Manufacturing

The *ferrous* metals include iron, manganese, and chromium. All other metals are categorized as *non-ferrous*. The *countries* that are *leaders* in *steel* making include the following (million tons, in 2006): (1) China, 423; (2) Japan, 116; (3) the United States, 98.6; (4) Russia, 70.8; and (5) India, 49.5. The *worldwide production* is

Photo 9.10 Gaseous pollutants of ferrous metallurgy enterprises include the following substances: (1) sulphur dioxide related to the presence of sulphur in fuels or ores, (2) nitrogen oxides emitted to the atmosphere as combustion products, (3) carbon monoxide, and (4) gaseous fluorides and chlorides. The most serious gaseous emission is sulphur dioxide. Emissions of the Cherepovets iron and steel plant (Russia) are shown here (Photo credit: V. Kantor, Greenpeace Russia, 31 of May 2010)

1,250 million tons. As for *iron* smelting, the following countries *lead* (million tons, in 2006): (1) China, 414; (2) Japan, 84.3; (3) Russia, 52.4; (4) the United States, 37.9; and (5) Ukraine, 32.9. In all, 881 million tons were smelted in the world in that year (Russia and countries of the world 2008).

Some of the major *sources* of the environmental effects of ferrous metallurgy include (Nature-conservative aspects in ferrous metallurgy 1986a) blast and open-hearth furnaces, blast-furnace slag granulation plants, converters, ferroalloy complexes, steel continuous casting plants, etching rooms, sintering machines, pellet firing machines, and crushing-milling equipment.

Ferrous metallurgy influences the following natural *components* and parameters: (1) atmosphere; (2) surface waters; (3) soils; (4) anthropogenic physical effects (thermal, noise, vibration, etc.); (5) geological environment; (6) withdrawal of land; and (7) visual impact. Indirect effects are also exerted on other components (vegetation, animal world, underground waters, etc.).

The effects on *atmospheric air* are expressed as pollution with solid and gaseous substances. The *former* are subdivided into coarse-grained dust particles that settle on the ground near the plants and micron and submicron particles ('suspended dust') that can be transported for long distances (Zhuchkov et al. 2002).

Dust is formed at practically all stages of production, but especially in the course of operation of blast, steel-making, ferroalloy, and coke-fired furnaces; agglomeration plants; and lime burning plants (Yanin 2004b). The *chemical composition* of the dust is as follows: iron, 50–70%; and calcium and magnesium compounds, 1–20%. The remainder includes aluminium, potassium, and titanium in the form of oxides, sulphides,

Photo 9.11 Blast and open-hearth furnaces are among the major sources of the environmental effects of ferrous metallurgy. The photo shows a metallurgist working by the blast furnaces in the Třinec Iron and Steel Works. It produces over a third of all steel generated in the Czech Republic (roughly 2.5 million tons annually) (Photo credit: http://en.wikipedia.org/wiki/Steel_mill)

carbonates, phosphates, and silicates (Dyakonov and Doncheva 2002).

In Russia, the contribution of ferrous metallurgy to pollution of the atmosphere with dust is 13.3% of that for all industrial branches. In the United States, for annual steel production of about 125 million tons per year, the amount of iron-containing dust that is formed reaches 16–17 million tons per year. In addition, 13 million tons of non-metallic dust is emitted that is dispersed in the environment (Yanin 2004b).

The following substances are prevalent in the composition of *gaseous pollutants* (Nature-conservative aspects of steel making 1986b; Sultaguzin et al. 2002): (1) sulphur dioxide related to a presence of sulphur in fuels or ores, (2) nitrogen oxides emitted to the atmosphere as combustion products, (3) carbon monoxide, and (4) gaseous fluorides and chlorides. The *most serious* gaseous emission is *sulphur dioxide*. Its major *sources* are (1) ore agglomeration lines, (2) coke-oven batteries, (3) blast furnaces, and (4) steel-making units.

The *share* of ferrous metallurgy in the pollution of the atmosphere with gases is 15.5% in Russia (Yanin 2004b) and 10% in Japan (An approach to recycling of resources in Japan 2004). Integrated iron-and-steel works, with capacities of 2–10 million tons of steel a year, emit 10,000–42,000 ton of sulphur dioxide; 7,000–32,000 ton of nitrogen oxides; and 80,000–430,000 ton of carbon monoxide every year (Sultaguzin et al. 2002).

The influence of ferrous metallurgy on *surface waters* is quite strong. Ferrous metallurgy works are significant sources of waste waters. The average specific volume of waste waters is 11.3 m^3/ton of steel.

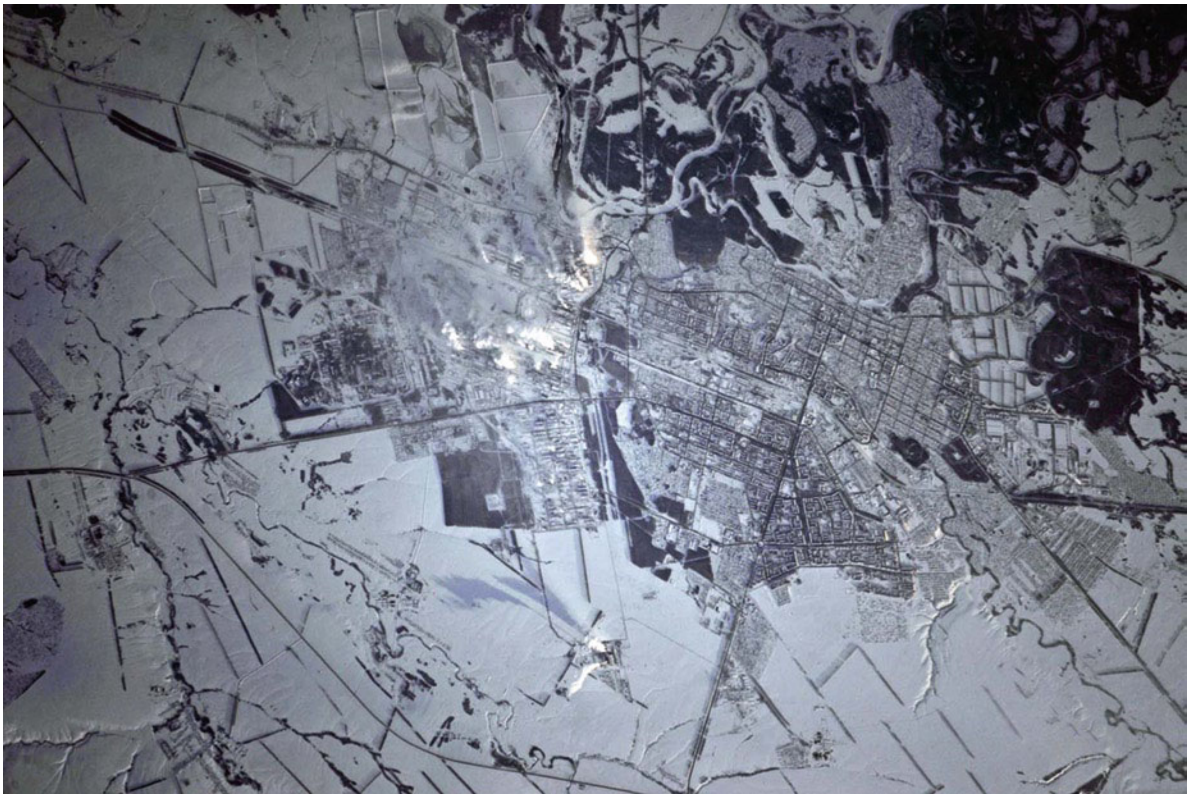

Photo 9.12 Dust is formed at practically all stages of steel production, but especially in the course of operation of blast, steelmaking, ferroalloy, and coke-fired furnaces; agglomeration plants; and lime-burning plants. The chemical composition of the dust is as follows: iron, 50–70%; and calcium and magnesium compounds, 1–20%. This space image shows the Orsk-Khalilovo Steel Works (Orenburg oblast, Russia). One can see that the snow cover in the *upper-left* portion of the photo is more intensely polluted due to transport by the prevailing winds (Photo credit: Russian Space Agency)

Metallurgical works, with capacities of one million tons of steel a year, discharge 18,000 m^3 of sewage every day; high contents of suspended matter are characteristic of this sewage (exceeding background levels by a factor of 10). The discharges of a number of works are highly toxic alkalis with pH levels of 12–13 (Doncheva and Pokrovsky 1999).

Soils are contaminated in the course of storage of raw materials and waste. The smelting of 1 ton of cast iron and steel is accompanied by the formation of 0.2–1 ton of slag. Blast-furnace slag consists of oxides of the following elements: silicon (40–44%); calcium (30–50%); aluminium (5–16%); magnesium (1–7%); iron (0.2–4.5%); and manganese (0.5–3%). Steel-smelting slag differs from blast-furnace slag in its higher content of iron and manganese oxides (Rudsky and Sturman 2006). Pollution is caused by both *wind transport of dust* from areas where solid waste is stored and by *precipitation scavenging* of harmful substances from waste storage facilities and from dust and gaseous discharges.

The effects on the *geological environment* are caused by large volumes of earthworks during the construction of enterprises. In the course of construction of a rolling-mill shop with five rolling mills and a yield of four million tons of rolled metal a year, 9.8 million cubic metres of ground is extracted (Khazanov 1975).

Ferrous metallurgy exerts different *anthropogenic physical actions*. *Thermal pollution* generally affects surface waters. About 75% of the water needed for production of cast iron and steel is spent for cooling. This water contains significant quantities of heat, which affects the *ichthyofauna* of receiving water bodies.

The *noise* sources are subdivided into three basic *classes* (Nature-conservative aspects of steel making

1986b): (1) mechanical noise (rolling mills, forge shops, and processing and transportation of products); (2) aerodynamic noise (fans, compressors, and valves); and (3) electrical noise (electric furnaces). The noise impacts arise in the shops rather than in the outside environment. In some enterprises, the levels of *vibration* caused by fans, combustion units, gas and smoke flues, etc. are considerable.

Iron and steel plants rank among the greatest industrial complexes, and they require significant *withdrawal of land*. In order to produce 1 ton of cast iron, 20–30 ton of rocks are extracted from deep in the earth, and certain areas are used on the ground surface for opencast mines, waste banks, and tailing dumps (Pevzner 2003).

Vegetation is subjected to indirect impacts. According to data obtained by Chernobayev (1990), within the ferrous metallurgy enterprise zone, the productivity of corn used for silage preparation decreases by 43%; that of horse beans decreases by 36%; that of cereal crops, by 26–27%; and that of sugar beets, by 55%. In the steppes of southern Russia, pollution with heavy metals, especially zinc, copper, and nickel, is observed (Dyakonov and Doncheva 2002).

The effects of ferrous metallurgy on the environment are illustrated by Photos 9.10–9.12.

9.2.2 Non-ferrous Metal Manufacturing

Non-ferrous metallurgy is a much more complex branch than ferrous metallurgy. A vast variety of different facilities, methods, and processes is characteristic of this branch of industry. Accordingly, the compositions of discharges to the atmosphere and water bodies are also different, related, first of all, to the raw materials that are used.

One of the peculiarities of non-ferrous metal *ores* is the fact that they contain relatively small amounts of the base metal. For example, the *content* of copper in ores infrequently exceeds 5%; zinc and lead, 6–7%; and molybdenum, only 0.1–0.2%. The *exception* is ores of aluminium, which contain not less than 30% of the base metal (Rudsky and Sturman 2006).

Based on their *physical properties* and purposes, the non-ferrous metals are conditionally divided into *heavy* (copper, lead, zinc, tin, and nickel) and *light* (aluminium, titanium, and magnesium). In addition, one can also identify *small* (antimony, mercury, and cadmium); *alloying* (tungsten, molybdenum, vanadium, and cobalt); *precious* or *noble* (gold, silver, and platinum); and *rare* and *scattered* metals (zirconium, niobium, tantalum, lithium, beryllium, selenium, and tellurium) (Ratanova 1999).

There are different *techniques* for producing non-ferrous metals from ores or concentrates: (1) pyrometallurgical, (2) electrometallurgical, and (3) hydrometallurgical. The two first techniques are the most commonly encountered and, at the same time, the most adverse from the viewpoint of environmental pollution (Tarasov 2002).

The *major polluters* in non-ferrous metallurgy are sintering furnaces and calcining kilns, electrolyzers, crushing-milling equipment, continuous transport mechanisms, and areas of material loading, unloading, and overturning (Grachev 1995). The *major smelted metals* are copper, lead, zinc, nickel, and aluminium.

This industry affects the following natural *components*: (1) atmospheric air, (2) surface waters, (3) condemnation of land, (4) soils, (5) vegetation, and (6) the animal world.

In accordance with data presented by Yu.V. Novikov (1999), basic pollutants of the *atmosphere* associated with this industry are sulphurous anhydride (75% of total emissions into the atmosphere); carbon monoxide (10.5%); and dust (10.4%). The pollution of the air with *sulphur dioxide* is generally observed when lead, antimony, copper, and zinc are smelted from sulphide ores. Non-ferrous metallurgy is the source of about 25% of total industrial emissions of sulphides (Stefanyuk 1994).

For example, in the course of producing 1 ton of *copper,* 8.3 ton of sulphur dioxide is emitted into the atmosphere. On the whole, the production of copper is responsible for approximately 13% of anthropogenic sulphur dioxide emitted into the atmosphere (Modern global changes 2006, vol 1). In the production of *magnesium*, in addition to sulphurous anhydride, the atmosphere is polluted with chlorine and hydrogen chloride (hydrochloric acid) (Dyakonov and Doncheva 2002). The *aluminium* industry also discharges anhydrous hydrogen fluoride and carbonic oxide (Burkat and Smola 2006).

The major *sources* of *dust* are furnaces of different types, concentrate dryers, and crushing-milling equipment. Very high concentrations of heavy metals and other chemical elements, reaching some tens of percents of the dust mass and exceeding many times their content in ores, are characteristic of the dust emissions (Yanin 2004b).

Photo 9.13 At the current level of technology, all primary sulphide ores of copper sulphides, and most concentrates of secondary copper sulphides (chalcocite), require smelting to produce copper from the sulphide minerals. Some experimental hydrometallurgical techniques to process chalcopyrite are being investigated, but as of 2009, they were unproven outside of laboratories. The photo shows froth flotation cells at a copper-nickel ore processing plant, Falconbridge, Ontario, Canada (Photo credit: http://en.wikipedia.org/wiki/Copper_extraction_techniques, 1973)

In the production of 1 ton of blister copper, about 2 ton of dust containing approximately 15% copper, 60% ferric oxide, and 4% each of arsenic, mercury, lead, and zinc are discharged into the atmosphere (Course of lectures on general and ecological chemistry 1993). In Russia, non-ferrous metallurgy delivers to the atmosphere about 10.5% of all industrial emissions of dust (Yanin 2004b).

Non-ferrous metallurgy is the greatest polluter of *surface waters*. The waste waters of the enterprises contain particulate pollutants, oil products, ions of heavy metals, sulphates, chlorides, fluorides, and other substances (Ratanova 1999).

The smelting of non-ferrous metals consumes a great deal of water. For example, the *following volumes of water* are used for production of the following metals: nickel, 4,000 m^3/ton; tungsten and molybdenum, 2,500; titanium, 1,000 (Rudsky and Sturman 2006); aluminium, 1,500; copper, 5,000 (Lukanin and Trofimenko 2001); lead and zinc, 360; and tin, 750 m^3/ton (Ratanova 1999). In the former USSR, non-ferrous metallurgy consumed about 10 billion cubic metres of fresh water every year, which corresponded approximately to 10% of total industrial withdrawal of water (Perederiy and Mishevich 1991).

The enterprises of non-ferrous metallurgy are among the largest industrial complexes, and they require considerable *withdrawal of land*. Taking into account the fact that, for example, non-ferrous metals are extracted from ores which generally contain several grams to several kilograms of commercial component per ton, large areas are occupied for waste storage.

In the vicinity of metallurgical combines, intense pollution of *soils* is recorded that is generally related to admixtures coming from the atmosphere. For example, investigations near the Irkutsk aluminium smelter (Russia) showed more than hundredfold increases in contents of fluorine, aluminium, manganese, barium, and sodium as compared with their background levels in soils (Belozertseva 2002). As a rule, increases in soil acidity occur near aluminium smelters (Vazhenin 1986).

The effects on *vegetation* are related to pollution of air and soils. For example, in the vicinity of a metallurgical complex in Ontario (Canada), within 16 km of it, 25 species of plants were found to be growing under normal conditions. As one grew closer to the complex, the number of plant species was found to have decreased, and at a distance of less than 1.6 km, none of the plants were found (Strauss and Mainwaring 1989).

Photo 9.14 The photo shows the Zinc Works and Incat shipyard in Hobart, Tasmania. It is the largest exporter in Tasmania, generating 2.5% of the state's GDP. It produces over 250,000 ton of zinc per year. The zinc works were historically responsible for high heavy metal levels in the Derwent river (Photo credit: http://en.wikipedia.org/wiki/Heavy_industry, 7 July 2009)

Photo 9.15 Large amounts of toxic waste are characteristic of many enterprises in non-ferrous metallurgy. Accidents are frequent at their storage facilities. For example, such an accident occurred on 9 October 2010 at the aluminium plant in Ajka, Hungary. This is a natural-colour satellite image, showing the north-western corner of the collapsed dam of Reservoir No.10, which released about 700,000 m^3 of highly alkaline and caustic red mud. The villages of Kolontar and Devecser were affected by this toxic spill (Photo credit: F. Lamiot, DigitalGlobe, 9 October 2010)

The influence of chemical pollution of soils on vegetation was revealed in the course of a detailed study of the environmental impacts of the *Monchegorsk metallurgical complex* (Russia). It is a great enterprise for nickel production situated within the taiga zone in north-western Russia. Soil samples were taken within the industrial zone of the complex and in uncontaminated sections. These soils were subsequently planted with spruce and pine seedlings.

It was revealed in the course of the experiment that the numbers of lost germs in the soil from the industrial zone for spruce and pine were five and three times *larger* than that in the control group, respectively. The ratios of surviving seedlings were 1:6 for spruce and 1:3 for pine (Chernenkova et al. 1995). According to data presented by Chernobayev (1990), within the zone of metallurgical works, the harvesting yield declines, on average, at the following *rates*: corn for silage by 43%, horse beans by 36%, cereals by 26–27%, and sugar beets by 55%.

The effects on the *animal world* are also indirect and are related to contamination of the soil and vegetation. Within different sectors of the affected zone around the

Monchegorsk metallurgical complex, the numbers of soil invertebrates were 6–14 times lower as compared with uncontaminated territories, while the total biomass was 10–12.6 times smaller (Chernenkova et al. 1995).

Studies in the vicinity of a copper plant in Poland showed excessive concentrations of lead, copper, and zinc in the blood, liver, kidneys, and muscular tissue of cows grazed within the zone of its emissions. Accumulations of large amounts of lead resulted in pathological changes in organs (Monkieurcz et al. 1986).

The effects on natural resources are expressed indirectly through the great *power* and *fuel intensity*. The production of aluminium (16,000–18,000 kWh of electric power per ton), magnesium, and titanium requires especially large amounts of power. The production of nickel (50–55 ton of equivalent fuel per ton), alumina of nepheline raw materials, black copper, and other non-ferrous metals also consumes large amounts of fuel (Geographical encyclopaedic dictionary 1988).

As compared with *ferrous* metallurgy, non-ferrous metallurgy is a *much more adverse industry* from an environmental viewpoint.

The effects of non-ferrous metallurgy on the environment are illustrated by Photos 9.13–9.15.

9.3 Mechanical Engineering

Mechanical engineering is the most complex and differentiated branch of industry. Based on the product range, mechanical engineering is subdivided into the following *activities*: (1) general engineering, (2) transport engineering, (3) electrical manufacturing industry, (4) agricultural engineering, (5) instrument engineering, (5) arms production; and others (Rodionova 2000).

Mechanical engineering is developed to the *greatest extent* in the United States (almost 30% of total engineering products); Japan (15%); the Federal Republic of Germany (10%); France; Great Britain; Italy; and Canada (Vavilova 2003).

Large-scale engineering works generally include the following *departments*: (1) power producing, (2) foundry, (3) rolling, (4) machining, (5) galvanizing, (6) assembling, and (7) painting (Govorushko 1999).

Based on their *effects* on the environment, the power-producing departments (boiler plants) do not differ from thermal power plants, while the environmental effects of foundries and rolling plants can be considered to be not as great as those of iron and steel plants. Therefore, they are not considered here.

In *machining* shops, metalworking is performed, which includes turning, milling, grinding, drilling, forge-and-press, welding, and other kinds of work. The most complex kind of work is metal cutting; it accounts for about 40% of the finished product value (Ratanova 1999).

The goal of the *electroplating* industry is deposition of metal, alloy, and chemical conversion (phosphate, oxide, etc.) coatings. According to *kinds of coatings*, the volume of output is subdivided as follows (percent): zinc plating, 58.8; nickel plating, 10.0; copper coating, 8.4; chromium plating, 8.4; cadmium plating, 4.6; and tinning, 2.7 (Zapolsky and Obraztsov 1989). Every year, several billion square metres of metal surfaces are processed; 50% of the cadmium produced, 25% of the tin, and 15% of the nickel is spent for these purposes (Bek 1991).

In applying coatings, the following working *operations* are performed (Electrolytic metallurgy 1987): (1) etching, (2) degreasing, (3) activation, (4) applying special electroconductive layers, (5) applying metal coatings, and (6) special treatment of coatings.

There are two *types* of *assembling* works: (1) stationary (all components and units are fed to one place, the assembly stand) and (2) mobile (yet-to-be-assembled units move successively through all stands). In *paint* shops, the paint-and-lacquer coatings are applied to the finished products.

In the *electrical manufacturing* segment of mechanical engineering, various units are made for energy generation, transmission, conversion, and consumption; means of communication and electrical measuring instruments; and different manufacturing equipment. The production of batteries, fluorescent lamps, and mercury thermometers has the greatest effect on the environment (Yanin 1998).

Mechanical engineering affects the following environmental *components* and parameters: (1) atmospheric air, (2) surface waters, (3) underground waters, (4) soils, and (5) noise pollution.

The effects of mechanical engineering on *atmospheric air* are significant. In Russia, it accounts for 4% of dust emissions and 4.2% of gaseous matter discharged (Yanin 2004b). Atmospheric pollution takes place at different stages of mechanical engineering activities. During *machine working* of metals, particles of worked materials, and sublimates and fumes of lubrication-cooling

Photo 9.16 There are two types of assembling works: (1) stationary (all components and units are fed to one place, the assembly stand) and (2) mobile (yet-to-be-assembled units move successively through all stands). The photo shows the assembly plant of the Bell Aircraft Corporation at Wheatfield, New York (United States). The aircrafts in the photo are Bell P-39Q-30-BE Airacobra fighters and Bell P-63A-8-BE Kingcobra fighters (Photo credit: http://en.wikipedia.org/wiki/Factory, 1944)

fluids enter the air. Pollutants that enter the atmosphere with emissions include oxides of sulphur, nitrogen, and carbon, as well as chlorine, abrasive dust, aerosols, and vapours (Kamenskaya et al. 1992; Popova 2006).

The chemical composition of pollutants caused by *welding* works depends largely on the composition of the welding materials (wire, coatings, and fluxing agents). In the consumption of 1 kg of welding electrodes for manual welding of steel, about 40 g of dust, 2 g of anhydrous hydrogen fluoride, and 1.5 g of carbon and nitrogen oxides are generated. In the case of autogenous and plasma arc *cutting* of metals, the air is polluted with toxic compounds of chromium, manganese, and oxides of carbon and nitrogen (Etin et al. 2003).

The harmful substances entering the air from *galvanizing* plants are in the form of dust, fine fog, vapours, and gases. The processes of acid and caustic etching, as well as plating (blackening, anodizing, phosphating, etc.), are most unfavourable.

In *paint* shops, the fumes of organic solvents, paint-and-lacquer materials, and pigment aerosols predominate (Ratanova 1999). In *battery* factories, the air is contaminated with dust containing lead, nickel, cadmium, arsenic, bismuth, antimony, and tin (Yanin 2004b).

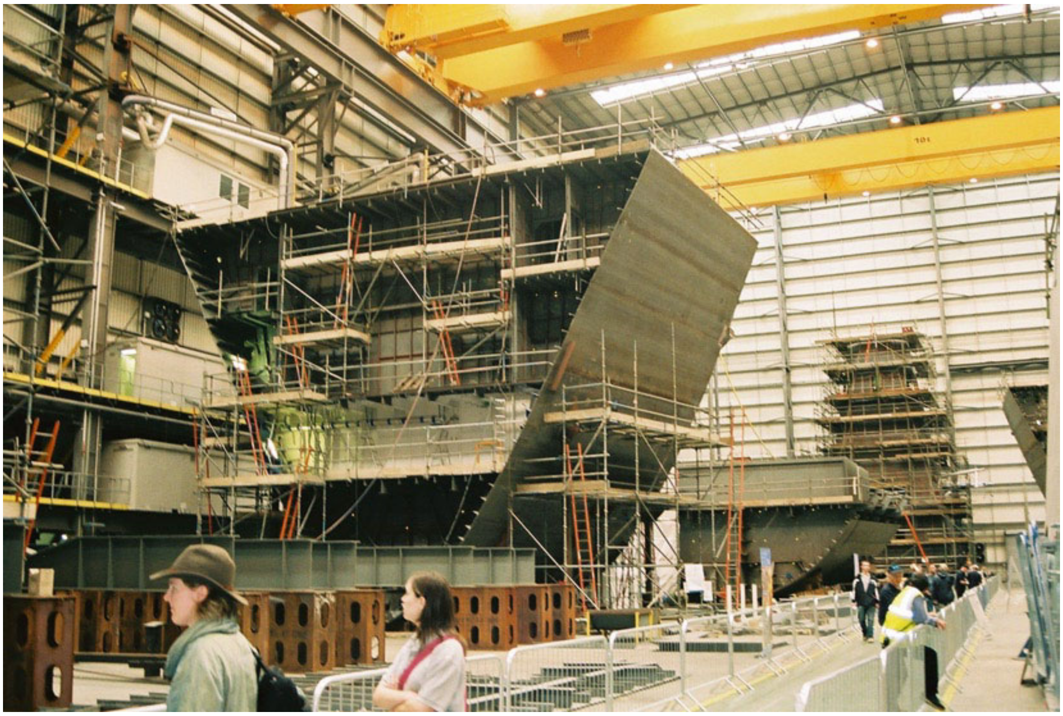

Photo 9.17 The distinct feature of mechanical engineering is the significant share of operations related to machine working of metals. Particles of worked materials, and sublimates and fumes of lubrication-cooling fluids, enter the air during these operations. Pollutants that enter the atmosphere with emissions include oxides of sulphur, nitrogen, and carbon, as well as chlorine, abrasive dust, aerosols, and vapours. The photo shows construction of prefabricated module blocks of HMS *Dauntless* at BAE's Portsmouth shipyard (Photo credit: Adrian Jones, 2 July 2005)

In factories making *thermometers,* the emission of mercury occurs. For example, in the Klinsky thermometer factory in Russia, annual emissions of mercury vapour reach 8–9 kg (Yanin 2004a). Emission of mercury vapour is also characteristic of the production of *fluorescent lamps.* The volume of emitted mercury on a global basis is estimated at 100–120 ton/year (Yanin 1998). Contamination with heavy metals is also characteristic of the production of *fluorescent lamps* (Skopina 2002).

The major source of pollution of *surface waters* in the course of *metalworking* is the discharge of used lubricant-cooling agents, electrolytes and washing agents containing oil products, soluble metal compounds, suspensions, and harmful chemical elements.

The waste waters of *galvanizing* activities generally contain cations (copper, zinc, nickel, cadmium, chromium, lead, mercury, iron, aluminium, tin, bismuth, cobalt, manganese, etc.) and their hydroxides (in the form of suspensions and colloidal particles), and anions (chlorides, sulphates, fluorides, cyanides, nitrates, nitrites, phosphates, etc.), as well as surfactant species (Bek 1991; Environment 1999, vol 1).

Galvanizing activities are among those with the *greatest water consumption*. It accounts for 20–50% of the total water usage of mechanical engineering enterprises (Electrolytic metallurgy 1987). Of particular importance is the workpiece flushing process performed after most manufacturing operations. This process accounts for

Photo 9.18 The chemical composition of pollutants caused by welding works depends largely on the composition of the welding materials (wire, coatings, and fluxing agents). In the consumption of 1 kg of welding electrodes for manual welding of steel, about 40 g of dust, 2 g of anhydrous hydrogen fluoride, and 1.5 g of carbon and nitrogen oxides are generated. Welding is dangerous, and precautions must be taken to avoid burns, electric shock, poisonous fumes, and overexposure to ultraviolet light. A man who is doing a gas metal arc welding is shown here (Photo credit: William M. Plate Jr., 12 January 2004)

Photo 9.19 In battery factories, the air is contaminated with dust containing lead, nickel, cadmium, arsenic, bismuth, antimony, and tin. The photo shows a worker who is ladling molten recycled lead into billets in a lead-acid battery recovery facility. Lead is an extremely toxic substance, and workers must be protected from its effects (Photo credit: National Institute for Occupational Safety and Health, United States, 18 June 2008)

about 70–80% of water consumption and 30% of water contamination by this industry. The second most important source of contamination is the ‘used’ electrolytes, which account for 30% of the contamination but only 1–2% of the waste water volume (Bek 1991).

A large contribution is made by mercury contamination in the manufacture of *thermometers* and *fluorescent lamps*. For example, in the Klinsky thermometer factory, about 70 kg of mercury was discharged with waste waters to the Sestra River every year (Yanin 2004b).

The pollution of *soils* is generally related to solid waste storage. The waste is mainly composed of chips and filings of ferrous and non-ferrous metals, and scale and sludge from the electroplating industry. For example, the machine work of ferrous metals results in irretrievable losses of 5.4%. The sludge of settling boxes contains toxic compounds of lead, chromium, copper, and zinc (Engineering ecology 2003).

The storage of *other wastes* also affects the *soils*. In the dump of the Klinsky thermometer factory, which has functioned for 37 years, about 140,000 ton of mercury thermometer fragments have been stored. The mass of mercury accumulated there is estimated to be at least 112 ton (Yanin 2004b).

Effects on *underground waters* are observed fairly often. For example, 35% of the total amount of mercury contained in underground waters in Sweden is from burned batteries (Yanin 1998). *Noise pollution* is especially high in the course of machine working of metals. For example, it reaches 115–130 dB in press shops (Rudsky and Sturman 2006).

Apparently the effects of mechanical engineering on *surface waters* are the *most harmful*, related to high water consumption and considerable contamination of discharges.

The effects of mechanical engineering on the environment are illustrated by Photos 9.16–9.19.

9.4 Building Materials Industry

The products of the *building materials industry* are natural and man-made materials and articles applied in the construction and repair of buildings and other structures. The basic *kinds* of materials are (Vainshtein and Vainshtein 2003) (1) natural rock materials and their products (sand, gravel, crushed stone, etc.); (2) binding materials of inorganic (cement, lime, gypsum, etc.) and organic (bitumen, tars, etc.) origin; and (3) artificial rock materials and products (brick, tile, glassware, concrete products, etc.).

According to data presented by V.P. Zhuravlev and co-authors (1995), the building materials industry accounts for 10% of all pollution. This industry affects the following environmental *components* and parameters: (1) atmospheric air, (2) soils, (3) surface waters, (4) geologic environment, (5) condemnation of land, (6) thermal pollution, and (7) radioactive contamination.

The adverse effects on the *atmosphere* are generally caused by *dust* discharges. In Russia, for example, 11.4% of total industrial discharges of solid waste are attributed to the construction industry (Yanin 2004b). The major *sources* of its delivery to the atmosphere are cement mills, lime kilns, carbonate of magnesia production plants, brick kilns, and asphalt processing units (Bretschneider and Kurfurst 1989).

For example, raw materials for *cement* production include limestone, chalk, and, more rarely, marbles, marls, travertine, and fusible clays and clay loams (Geographical encyclopaedic dictionary 1988). For the production of 1 ton of cement, about 3 ton of lump material must be crushed, milled, burnt, and carried. This material is almost completely transformed into fine dust consisting of a mixture of calcium carbonate ($CaCO_3$), calcium oxide (lime, CaO), and other substances (Vainshtein and Vainshtein 2003).

Dust that is extremely detrimental to health arises in the manufacture of goods from *natural rock materials*. The major manufacturing operations producing dust include (Bretschneider and Kurfurst 1989) (1) crushing, (2) cracking, (3) transfer to charging grid, (4) transportation, and (5) storage. Production of *lime* is accompanied by discharge of about 200 kg of dust per ton of output products, while 140 kg is discharged in the production of 1 ton of gypsum plaster (Sokolov 1988).

In the manufacture of *lime sand brick*, the ‘dirtiest’ operations are charging of limestone and sand by cranes, transportation, sorting with sifters, and pressing (Primak and Baltrenas 1991). In the course of producing *ceramics* and *clay brick*, the maximum escape of dust is characteristic of the chamotte milling division and batch preparation shops (Vakunin and Koryakov 2005).

Some factories manufacturing building materials emit, in addition to dust, large quantities of *gaseous pollutants*. For example, the world’s cement industry

Photo 9.20 For the production of 1 ton of cement, about 3 ton of lump material must be crushed, milled, burnt, and carried. This material is almost completely transformed into fine dust consisting of a mixture of calcium carbonate, calcium oxide, and other substances. The photo shows a precalciner tower, rawmix silo, and exhaust stack. *Bottom left*: rawmill. *Bottom right*: rotary kiln with tertiary air duct above. The U-shaped duct leading from the kiln inlet is an 'alkali bleed' (Photo credit: http://en.wikipedia.org/wiki/Cement_kiln, 2 June 2007)

accounts for 1.5% of anthropogenic discharges of carbon dioxide (Yudovich et al. 2005). The cement industry ranks third in this characteristic in the European Community (Szabo et al. 2006).

Increased gas emissions are also characteristic of *asphalt* production. In this case, the major source of emissions is the drums for asphalt-concrete mix preparation, to which the mineral components are delivered and where they are mixed with a binding component, bitumen (Dorozhukova and Yanin 2004). The volumes of waste gases (carbon monoxide, nitrogen dioxide, sulphurous anhydride, and volatile hydrocarbons) are, in this case, 200–600 m^3/t of the mixture (Zheltobryukhov et al. 2000).

The manufacture of *sanitary ware* is accompanied by emissions of up to 200 kg of carbon oxides per ton of product (Sokolov 1988). The smoke fumes caused by glassmaking contain the following (milligrams per cubic metre): fluorides, 150; arsenic oxides, 55; boron oxides, 1,300; and sulphur oxides, 375 (Menzelintseva and Artemova 2006). The *other harmful components* of waste gases emitted during the production of building materials are nitrogen oxides and carbohydrates.

Effects on *soils* are observed particularly in the course of coating plant operation and transportation of asphalt. A number of chemical elements enter the soil, including zinc, copper, mercury, molybdenum, chromium, and lead (Dorozhukova and Yanin 2004).

Surface waters are polluted by the following *processes* (Environmental assessment sourcebook 1992): (1) fluid drainage from settling boxes used for dust soaking, (2) scattering of kiln charge, and (3) storage of raw materials and processing wastes. These processes result in pH increases and pollution with suspended and dissolved substances, predominately potassium and sulphates.

The influences on the *geological environment* are related to two *factors* (Govorushko 2009a): (1) processing of huge volumes of natural materials (sand, clay, crushed stone, limestone, etc.) and (2) excavation of large amounts of subsoil. For example, the volume of earthworks in the course of construction of a cement mill with a capacity of 1.2 million tons a year is approximately 1.3 million cubic metres (Khazanov 1975).

Condemnation of land is caused by the considerable quantities of waste. However, as a rule, these wastes are non-toxic or low in toxicity. In addition, a large portion is returned to production (Rudsky and Sturman 2006).

Thermal pollution is related to the fact that the manufacture of many kinds of products requires considerable expenditures of energy. For example, 1% of world energy consumption is used for the production of cement (Avrorin 1999). In order to produce one

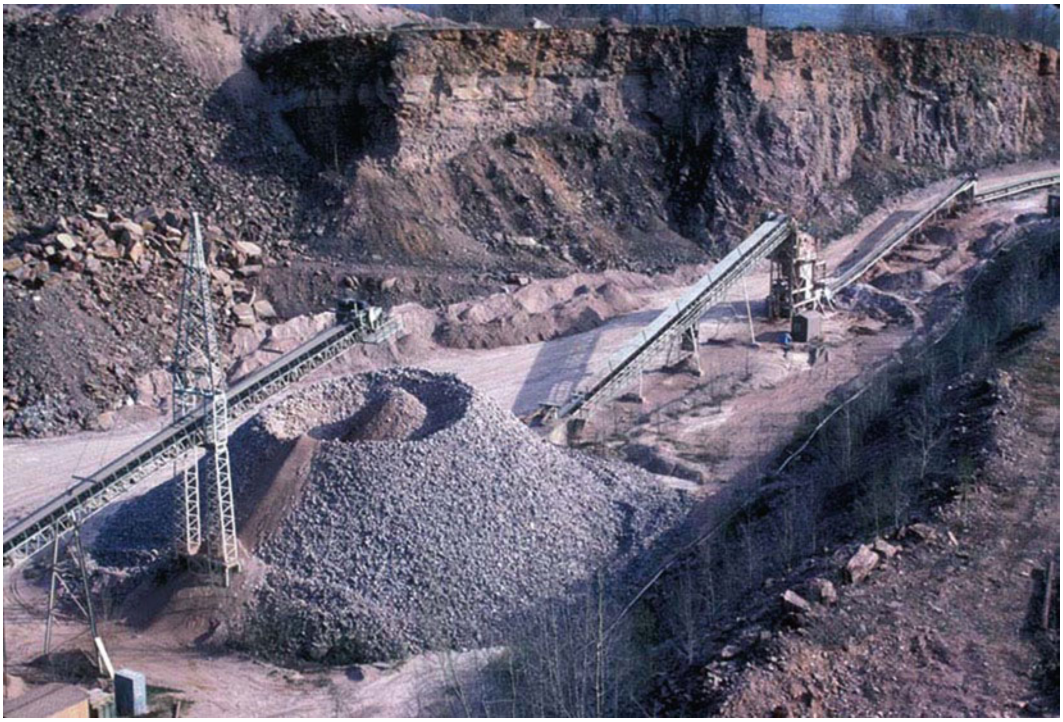

Photo 9.21 The manufacture of goods from natural rock materials also is accompanied by dust discharges. The major manufacturing operations producing dust include (1) crushing, (2) cracking, (3) transfer to charging grid, (4) transportation, and (5) storage. This dust is extremely detrimental to health. The photo shows a gravel quarry in Wisconsin (United States) (Photo credit: Marli Miller, University of Oregon)

ceramic brick, about 0.27 kg of the equivalent fuel is needed (Filatov 2005). Generally, energy is consumed in processes of hard firing (e.g. brick, tile, Dutch tile, and faience and porcelain sanitary ware items). The thermal pollution affects the atmosphere, surface waters (discharge of process cooling water), and soils.

Radioactive contamination is caused by the fact that some natural rock materials (granites, syenites, and porphyrites) are characterized by increased background radiation (Filatov 2005). On the whole, its role is not great.

Increased occupational morbidity, traumatism, and *mortality* are characteristic of the enterprises of the building materials industry. For example, in the plants of the building sector in Russia, more than 20,000 workers are injured every year, and more than 1,000 of them are killed (Koptev et al. 2003).

The effects of the building materials industry on the environment may have *positive* aspects. *First* of all, the kiln dust of cement mills can be used for liming of soils, neutralization of acid mine waters, stabilization of hazardous waste, or as asphalt filler. *Secondly*, cement technology is suitable for the use or destruction of various wastes (Filatov 2005).

The influences of the building materials industry on the environment are illustrated by Photos 9.20–9.22.

Photo 9.22 Some factories manufacturing building materials emit, in addition to dust, large quantities of gaseous pollutants. For example, the world's cement industry accounts for 1.5% of anthropogenic discharges of carbon dioxide. The cement industry ranks third in this characteristic in the European Community. The photo shows a cement factory in Primorsky Krai, Russia (Photo credit: A.M. Panichev, Pacific Geographical Institute, Vladivostok, Russia, 2004)

9.5 Woodworking Industry

The *woodworking industry* includes a complex of branches related to timber harvesting, and mechanical and chemical treatment and processing. It manufactures sawn goods, plywood, wood-based panels, furniture, matches, sleepers, and other products. Environmental consequences of timber harvesting will be considered in Sect. 11.2.1. In Russia, the number of people working in the industry exceeds five million (Lapkayev and Rogov 2005).

Mechanical processing of timber is conducted using machines. The basic *kinds* of woodworking machines and processes are: (1) sawing (band, circular, power-saw benches, trimming, multi-edgers, butting, and panel); (2) milling; (3) jointers; (4) panel planers; (5) turning; (6) four cutters; (7) drilling; (8) polisher; and (9) dovetail jointers.

Mechanical processing of wood is generally based on four working *operations*: (1) sawing, (2) planning, (3) drilling, and (4) polishing. As a result, sawn goods are produced that are used in construction, manufacture of furniture, finishing agents, musical instruments, sports goods, crafts, and so on (Nabatov 1997).

Chemical treatment of timber-based materials is used to make *wood fibreboard* (sheet material made of plexiform wood fibres by drying or hot-pressing) and *wood chipboard* (sheet material made by hot-pressing woodchips with binding materials).

The following countries *lead* in the production of *wood fibreboard*: (1) the United States, (2) China, (3) Canada, (4) the Federal Republic of Germany, and (5) Russia. The *leaders* in the production of *wood chipboard* are (1) the United States, (2) the Federal Republic of Germany, (3) Canada, (4) Belgium, and (5) Italy (Vavilova 2003).

Photo 9.23 Mechanical processing of wood is generally based on four working operations: (1) sawing, (2) planning, (3) drilling, and (4) polishing. As a result, sawn goods are produced that are used in construction, and manufacture of furniture, finishing agents, musical instruments, sports goods, crafts, and so on. The photo shows a wood processing department in Boulder, Colorado (United States) (Photo credit: Doug Page, U.S. Department of the Interior Bureau of Land Management, Bugwood.org, April 2002)

As to the extent of environmental pollution, the woodworking industry does not fall into the category of leading industries. For example, it ranks 10th among all industrial branches in Russia by volumes of atmospheric emissions and accounts for 2.9% of their total amount (Yanin 2004b). Woodworking has effects mainly on the following natural *components*: (1) atmospheric air, (2) soils, and (3) underground waters. In addition, it has serious impacts on human health.

The influences on *atmospheric air* are generally related to dust emissions produced in the course of mechanical treatment of timber, and gas discharges, in the case of chemical treatment. In 1991, the emissions of harmful substances by the Russian woodworking industry into the atmosphere reached 855,300 ton (Lapkayev and Rogov 2005).

Dust is fine, solid particles suspended in the air. It is *subdivided* into (1) *coarse* dust, which is visible to the naked eye; (2) *finer* dust, which is visible when passing through sunrays in the air; and (3) dust that is *invisible* to the naked eye.

The most intense dust formation is characteristic of radial saw, panel saw, band saw, and belt-grinding machines (Lomakin et al. 2005). For example, grinding machines produce 24–2,040 kg of dust per shift (Lapkayev and Rogov 2005).

Fine dust with particle sizes of less than 10 μm is most dangerous. In mechanical treatment of timber, this dust comprises about 65% of the total amount (Yanin 2004b). Among all kinds of mechanical processing, *grinding* (polishing) operations are most significant from this point of view. As to toxicity, the dust of the East Indian redwood, or sapanwood tree, is the most dangerous, followed by ash, larch, pine, birch, and oak dust (Lapkayev and Rogov 2005).

The *waste* volumes of the mechanical processing of timber are relatively small. For example, they are 3–6% in the timber works of British Columbia (Canada) (Orban

Photo 9.24 The waste of the mechanical processing of timber generally contains 34.5% bark, 15.4% sawdust, 8.5% cuttings, 21.9% chips, and 19.6% other waste. The photo shows the operation of a belt sawmill in Oregon (United States) (Photo credit: United Nations Educational, Scientific and Cultural Organization)

et al. 2002). They contain generally 34.5% bark, 15.4% sawdust, 8.5% cuttings, 21.9% chips, and 19.6% other waste (Yanin 2004b). When this waste is milled with the objective of further processing, more dust escapes.

Gaseous emissions are, to a great extent, related to the production of chipboard and include redolent terpene hydrocarbons and formaldehydes. For example, about 40 plants in the Federal Republic of Germany manufacturing chipboard discharged 4,600 ton of these organic compounds into the atmosphere in 1979 (Environment 1999, vol 1).

Emissions into the atmosphere are also related to the use of different *paintwork* materials in the manufacture of *impregnating* solutions designed to protect wood and sawn timber. Here, various organic and inorganic compounds are used, such as oil, surfactant species, acids, solvents, and salts (Popova and Kharuk 1991). Some contribution is also made by woodworking enterprises that emit oxides of carbon, nitrogen, and sulphur, and ozone (Shilova and Rogov 2001).

The influences on *soils* and *underground waters* are generally related to leaching from waste wood that is buried in the ground (Bassett 1996). A certain contribution is made by penetration into the soil of toxic preservatives in the course of impregnation and drying of timber, as well as their washout when preserved timber is used (Popova and Kharuk 1991).

The effects on human *health* are related to the release of dust. Three *types* of reactions of humans to wood dust have been identified: (1) primary irritations, (2) allergic reactions, and (3) systemic diseases (Lapkayev and Rogov 2005).

The *first group* is related to the irritation of mucous membranes, which is accompanied by rhinitis, lachrymation, nasal haemorrhage, and other reactions. The *allergic* reactions are more often expressed as itching, but whole-body dermatitis is possible. Many skin diseases are known that are caused by the wood dust of a number of tropical species. However, it is now known that the wood dust of many species of the temperate zone (spruce, pine, larch, linden, birch, maple, beech, and oak) is characterized by similar effects (Lapkayev and Rogov 2005).

The *third group* includes different diseases of the respiratory tract, eyes, and other parts of the body. Wood dust causes the occupational disease pneumoconiosis (Golovunina 2001). The oncogenic effect of beech and oak dust is considered to be proven (Environment 1999, vol 1).

In addition, a threat to people is related to the fact that, under certain conditions, wood dust is able to *ignite* and *explode* (Voronova and Avlokhova 2005).

The effects of the woodworking industry on the environment are illustrated by Photos 9.23 and 9.24.

9.6 Wood Pulp and Paper Industry

Cellulose is a component of plant cells that provides the mechanical strength and elasticity of plant tissues. It is basically used for the production of paper and cardboard. The following five countries *lead* in cellulose production (million tons): (1) the United States, 81.5; (2) China, 37.9; (3) Japan, 30.7; (4) Canada, 19.8; and (5) the Federal Republic of Germany, 17.9. As for the manufacture of paper and cardboard per capita, the following countries are in the lead (kilograms per year): (1) Finland, 2,360; (2) Sweden, 1,100; (3) Canada, 630; (4) Norway, 485; and (5) Austria, 475 (Maksakovsky 2006, vol 1).

Cellulose produced from the wood *of coniferous trees* is stronger, and its fibres are longer; however, cellulose can be manufactured from any plant. In simplified form, the *technological process* can be described as follows: Cuttings of logs (1–3 m long) are freed from bark and abraded into wood pulp. The wood pulp is bleached with hydrogen peroxide or sodium peroxide. Then the non-cellulosic substances (lignin, gums, mineral substances, etc.) are removed from the wood pulp.

There are two *methods* of cellulose production: (1) sulphite and (2) sulphate. In the *sulphite* method, the wood pulp is processed with a solution of calcium bisulphate and sulphuric acid. The processing is carried out in autoclaves at temperatures of 130–160°C and pressures of up to 6 atm. Within 10–16 h, most of the non-cellulosic substances have been dissolved, and, as a result, we have 95% cellulose. Then the cellulose is washed with water, dehydrated, and compressed (Ratanova 1999).

The sulphite method is primarily used for processing fir and spruce wood, while the sulphate method is suitable for processing any wood, including raw waste lumber and woodworking waste. The *first* method results primarily in pollution of surface waters, while the *second* (sulphate) method contaminates the air (Geoecological principles of design 1987; Filatov and Shpakov 2001).

The *sulphate* method of cellulose production includes the boiling of woodchips in white liquor (a mixture of sodium hydroxide [NaOH] and sulphureous sodium [Na_2S]) at 165–175°C for 3–5 h. The cellulose produced is washed, disintegrated, dried, and bleached. As in the sulphite method, a major pollution source is the bleaching shop (Ratanova 1999).

The pulp-and-paper industry influences the following natural *components*: (1) surface waters, (2) atmospheric air, (3) animal world, (4) soils, (5) underground waters, and (6) thermal pollution.

The effects on *surface waters* are basically observed in the case of the *sulphite* method of production. The waste waters arising in this case can be divided into the following *types*: (1) bark-containing waters (polluted with bark, which degrades water quality by releasing tarry matter); (2) fibre-containing waters (polluted with wood fibres and dyes that are deposited on the bottoms of water bodies; the fibres rot, emitting carbon dioxide and ammonia); (3) leachate-containing waters (contain lignin and tarry matter; disturb the oxygen regime of water bodies); (4) acid waters (contain mineral acids, including sulphuric acid; reduce pH and dissolved oxygen content); and (5) chlorine-containing waters (polluted with chlorine, alkali, and sulphuric and hydrochloric acids) (Shubnitsina et al. 2000; Shabalova and Tarasyavichute 2006).

In the *sulphate* method of production, the major effect is also related to leachate-containing waste waters. They include gums, phenols, hydrogen sulphide, methyl mercaptan, turpentine, methanol, and other substances. Sludge-containing waters are characterized by very high alkalinity (Ratanova 1999).

The pulp-and-paper industry consumes large quantities of water: for a production of 1 ton of cellulose, from 400 to 500 m^3 (Rudsky and Sturman 2006) to 1,000 m^3 (Environment 1999, vol 2) of water is needed. In the former USSR, this industry consumed 3.1 billion cubic metres of water every year (Sizov 1988).

Atmospheric pollution occurs as a result of emissions of dust and gaseous substances. The *solid particles* include sodium and calcium compounds, and particles of starch, talc, lime, clay, and pigments. The volumes of emissions may reach 283 kg/ton of the final product (Yanin 2004b). The *gaseous pollutants* include hydrogen sulphide, oxides of nitrogen and carbon, methyl mercaptan, dimethyl sulphide, terebenthene, and methanol (Romanova and Bratseva 2004; Turanchiyeva 2005).

The influence on the *animal world* is indirect and related to the pollution of water bodies with waste waters. For example, the discharge of leachate-containing waste waters reduces the water transparency, which decreases available sunlight and thus phytoplankton formation (Ratanova 1999). Many pollutants

Photo 9.25 Cellulose is a component of plant cells that provides the mechanical strength and elasticity of plant tissues. It is basically used for the production of paper and cardboard. The photo shows the process of cellulose making at the Baykalsky wood pulp and paper works (Russia) (Photo credit: V. Kantor, Greenpeace Russia)

Photo 9.26 Cellulose can be manufactured from any plant. However, cellulose produced from the wood of coniferous trees is stronger, and its fibres are longer. The photo shows timber storage for the St. Mary's Paper Company (on the Canadian side of St. Mary's River) (Photo credit: U.S. Environmental Protection Agency, Great Lakes Program Office)

Photo 9.27 The effects of wood pulp and paper plants on surface waters are basically observed in the case of the sulphite method of production. The waste waters are polluted with bark, wood fibres, lignin, tarry matter, mineral acids, chlorine, alkali, sulphuric and hydrochloric acids, and other substances. The photo shows a waste disposal basin at a paper company in Minnesota (United States) (Photo credit: U.S. Environmental Protection Agency, Great Lakes Program Office)

Photo 9.28 Atmospheric pollution associated with wood pulp and paper plants occurs as a result of emissions of dust and gaseous substances. The solid particles include sodium and calcium compounds, and particles of starch, talc, lime, clay, and pigments. The gaseous pollutants include hydrogen sulphide, oxides of nitrogen and carbon, methyl mercaptan, dimethyl sulphide, terebenthene, and methanol. The Arizona Chemical wood pulp mill in Panama City, Florida,, is shown here (Photo credit: K. Hite, Colorado State University, Fort Collins, Colorado, United States)

are toxic for hydrobionts. Moiseeva (2005) examined the stability of aquatic organisms to pollution with waste waters from sulphate cellulose production in north-western Russia. According to her data, daphnids (*Daphnia magna*), and larvae of whitefish (*Coregonus albula)*, salmon (*Salmo salar*), rainbow trout (*Parasalmo mykiss*), and pike (*Esox lucius*) experience the greatest toxicity.

The effects on *soils* are caused by dust that falls from the atmosphere and leakage of high-alkalinity waste. Data on soil changes near a paper-making plant in the Assam State (India) are given in a paper by Phukan and Bhattacharyya (2003). In the soils near the plant, an accumulation of aluminium oxide, iron (III) oxide, and manganese (II) oxide, as well as calcium, sodium, magnesium, and lead occurs; soil becomes alkaline, and its water retentivity and density decrease.

The effects on *underground waters* are also related to technological leakages. For example, 23 years after a Baykal pulp-and-paper plant was put into operation, between the industrial site and the edge of Lake Baykal, underground waters were found to be polluted with sulphate ion, hydrocarbonates, and a number of specific ingredients. In order to resolve this problem, 12 interceptive wells were drilled. Pumped underground waters were cleaned; in 1999, 474 m^3 was pumped (Gorkina 2009).

Thermal pollution is caused by the use of large volumes of water (flushing of cellulose, using water in heat exchangers and condensers for cooling, etc.) and then discharge of the heated water to water bodies.

The effects of the pulp-and-paper industry on the environment are illustrated by Photos 9.25–9.28.

9.7 Light Industry

Light industry includes such *branches* as the textile industry, clothing manufacture, tanning, shoemaking, the fur industry, and toy manufacture. The percentages of light industry of all industrial production are the *highest* in Turkey (16.6%), Portugal (15.2%), Vietnam (14.7%), Bulgaria (13.5%), and Morocco (12.0%) (Russia and countries of the world 2008).

The most important branch is the *textile* industry, which provides about half of the entire production volume and ranks first in the number of employed people (Maksakovsky 2006, vol 1). The absolute *leaders* here are China and India. For example, the manufacture of cotton clothes is characterized by the following *figures* (billion square metres): (1) China, 39.1 (2003); (2) India, 23.1 (2006); (3) the United States, 3.8 (2002); (4) Russia, 2.2 (2006); and (5) Italy, 1.3 (2004) (Russia and countries of the world 2008).

As for effects on the environment, the textile and tanning branches are of greatest importance. The basic *technological processes* of the textile branch are (1) raw material preparation, (2) spinning, (3) weaving, (4) painting and colouring, and (5) other finishing (addition of materials that decrease combustibility and improve colour fastness and extension resistance, and so on).

In the production of *leather*, the animal fells are subjected to the following *operating steps*: (1) preparatory processes (skin with hairs is changed into untanned, semi-finished goods; rawhide, at this step, it is preserved with salts, dried, and washed with solutions of chemicals, and the hairs are removed); (2) tanning (in order to increase resistance and elasticity, a skin is treated with chromium sulphate, sodium sulphate, and sodium carbonate); (3) trimming (foliation) of skin (natural skin has a thickness of about 1 cm; it is split into three to six layers); and (4) finishing operations (dyeing, malaxation, and greasing) (Poyarkov 2002).

Light industry has effects on the following *components* of the natural environment: (1) surface waters, (2) atmospheric air, (3) soils, and (4) the animal world. It also exerts serious influences on human health.

The effects on *surface waters* consist of their pollution with different substances. As for water consumption, light industry is among the leading branches of industry. For example, about 5% of the total water volume consumed by industry in Europe is used by the textile branch (Durig 1981).

Water use in the *textile branch* is basically related to processes of *cloth* washing at different stages of finishing. Water use varies with different types of clothing. According to data presented by Sadova and co-authors (2002), water consumption is 100–180 m^3/ton for silk clothes, 200–210 m^3/ton for cotton fabrics, and 260–270 m^3/ton for linen clothes. The greatest amount of water (300–330 m^3/ton) is required for the production of woollen clothes (Marinich et al. 2000). Water consumption in *leather making* is much lower: In the treatment of 1 ton of raw tanning products, 35 m^3 of waste waters is formed (Van Groenestijn et al. 2002).

Photo 9.29 One of the major kinds of raw material for the textile industry is sheep hair. The photo shows a sheep shearer (in France), a worker who uses (hand-powered) blade or machine shears to remove wool from domestic sheep during crutching or shearing (Photo credit: F. Vernois, United Nations Educational, Scientific and Cultural Organization)

Photo 9.30 The composition of waste waters generated during primary wool treatment depends on the housing conditions of the animals, the composition of cleaning solutions, and other factors. Waste waters are contaminated with pesticides (used for sanitizing sheep) and soil particles, and they contain particles of fat, soap, soda, surface-active materials, and wool. The photo shows Khashkaï women (nomadic shepherds) washing wool in the spring of Sarab Bahram, region of Noorabad, Province of Fars, Iran (Photo credit: http://fr.wikipedia.org/wiki/Tapis_persan, April 2007)

The *water pollution* caused by operating textile production units is basically related to cloth washing, colouring, and finishing. In the course of primary *wool* treatment, the composition of waste waters depends on the housing conditions of the animals, the composition of cleaning solutions, and other factors (Pugachev 1988). Waste waters are contaminated with *pesticides* (used for sanitizing sheep) and *soil particles* (Rogachev 2000),

Photo 9.31 The major contaminants in the tanning industry are chromium salts used for tanning, and cobalt, copper, and nickel, which are components of the colouring agents. In the treatment of 1 ton of raw stock, 200 kg of chlorides, 100 kg of sulphates, and 10 kg of trivalent chromium are formed. Tanneries of Marrakech (Morocco) are shown here (Photo credit: http://en.wikipedia.org/wiki/Tanning)

and they contain particles of fat, soap, soda, surface-active materials, and wool (Smirnov et al. 2000).

Much of the initial solutions is contained in the waste of *dye-finishing* production. For example, the amounts of thickeners, Glauber's salts, starch, and surface-active materials in the waste waters amount to up to 90% of their initial content in the finishing liquors; for sodium hydroxide, it is 50%; for dispersed and cationic dyes, 40%; for sulphur dyes, 30%; and for potassium dichromate, 25% (Kiselev 2002). Because the waste waters of textile mills are often heavily coloured, they also cause degradation of the visual quality of water downstream (Nevsky 2001).

In addition to substances used in dyeing-finishing operations, a significant share of pollutants in waste waters is represented by *chemicals* not used in the production process. Among these are washing agents for machines and apparatus, chemicals for cleaning boilers, biocides, and insecticides (Chavan 2001).

The major contaminants in the *tanning* industry are chromium salts used for tanning, and cobalt, copper, and nickel, which are components of the colouring agents (Rudsky and Sturman 2006). In the treatment of 1 ton of raw stock, 200 kg of chlorides, 100 kg of sulphates, and 10 kg of trivalent chromium are formed (Van Groenestijn et al. 2002).

Emissions into the *atmosphere* include dust and gases. In Russia, light industry is the source of 0.5% of solid particles delivered by all industrial branches (Yanin 2004b). Dust emissions are characteristic, first of all, of primary treatment of cotton, flax, and wool (Schepochkin and Tomin 2003). For example, in the course of flax fibre manufacture, the dust volume is 0.5–1.5% of the volume of the raw materials used (Yanin 2004b). Wool dust consists of particles of mineral and organic origin. Silicon dioxide, part of the mineral component, is the most dangerous (Smirnov et al. 2000).

Photo 9.32 Byssinosis, a disease of the lungs caused by inhalation of organic dust containing textile fibres, is characteristic of workers in shops conducting preliminary treatment for cotton and flax spinning mills. The photo shows a cotton factory in Niger (Photo credit: United Nations Educational, Scientific and Cultural Organization)

The composition of *gaseous pollutants* in the textile branch depends on the technological operation. In *bleaching* shops, where all processes occur at high temperatures, carbon monoxide, nitrogen dioxide, sodium hydroxide, and hydrogen peroxide are emitted into the atmosphere. In *dyeing-washing* shops, the air is polluted with sodium hydroxide, hydrogen sulphide, sulphur dioxide, ammonia, nitrogen dioxide, formaldehyde, and other compounds (Sadova et al. 2002).

In *finishing* shops, the major harmful substances are vapours of alkalis and acetic acid, carbon monoxide, sulphurous anhydride, formaldehyde, and nitrogen oxides (Marinich et al. 2000). In *engraving* shops, where chromium plating and etching of printing rollers are conducted, trivalent chromium oxide; nitric, hydrochloric, and sulphuric acids; and sodium hydroxide are emitted into the atmosphere (Sadova et al. 2002).

In the course of *leather* manufacture, the air is polluted with hydrogen sulphide, ammonia, and vapours of sulphuric and formic acids (Pisareva et al. 2003). Because polymeric materials are used for the manufacture of leather goods, and different glues (including those based on organic solvents) and dyes are widely applied, considerable amounts of toxic pollutants are released into the atmosphere (Mikhailyuk et al. 2003).

The pollution of *soils* occurs when pollutants settle out from the atmosphere and in waste storage. In *leather making,* chromium and lead are major pollutants. For example, in the street in Yaroslavl (Russia) where tanners worked in the Middle Ages, the concentrations of lead in the ground layers dating back to that time proved to be much higher than the current standards (Danilov-Danilyan et al. 2001).

The influences on the *animal world* are expressed through pollution of habitat. Discharges of waste waters cause living conditions for hydrobionts to deteriorate. For example, discharges of phenols and synthetic detergents poison fish (Kiselev 2002). Textile and tanning manufacture is a source of threats to wild animals. For example, *anthrax* episodes are known which appeared as a result of introduction of anthrax spores to pasture soils and water bodies by waste waters of tanneries and wool-scouring machines (Manual for general epizootology 1979).

Many occupational *diseases* are characteristic of light industry. For example, allergic asthma caused by pollen covering the wings of the *silkworm moth* and ursolic asthma of furriers (Pytsky et al. 1991) are known. Byssinosis, a disease of the lungs caused by inhalation of organic dust containing textile fibres, is characteristic of workers in shops conducting preliminary treatment for cotton and flax spinning mills (Environment 1999, vol 2).

The effects of light industry on the environment are illustrated by Photos 9.29–9.32.

9.8 Food Processing Industry

The *food processing industry* is a totality of facilities for producing ready-to-eat products and prepared foods, as well as tobacco goods, soap and other cleaning agents, perfumes, and cosmetics.

Based on scale and how they are arranged, these enterprises can be divided into two *categories*. The *first* category includes enterprises running on imported raw materials. They are located near ports, rail junctions, etc. Their products do not require immediate consumption, and they are highly transportable. They include producers of confections and beverages, flour-milling plants, the tobacco industry, and other enterprises.

The following enterprises fall into the *second* group: (1) those oriented toward raw materials (e.g. sugar, canning, meat processing, butter manufacturing, and cheese making) and (2) those oriented toward the consumer (baking industry, intermediate production, etc.) (Rodionova and Bunakova 1999).

In accordance with the raw material used, the enterprises of the food processing industry are divided into three *categories*: (1) those that run on raw stock of vegetable origin, (2) those that run on raw stock of animal origin, and (3) those that use non-agricultural raw materials. The functioning of many enterprises of this industry is characterized by pronounced seasonality.

The food industry has effects on the following natural *components*: (1) surface waters, (2) atmospheric air, (3) the animal world, and (4) condemnation of land. In addition, it seriously affects human health and results in high mortality.

The effects on *surface waters* are expressed as pollution with different substances: proteins, carbohydrates, fats, organic acids, spirits, aldehydes, and ketones (Baillie 1995; Environment 1999, vol 2). Sometimes, the contribution of the food industry to water pollution is principal. For example, in France it is the source of more than 70% of waste waters with increased content of nitrogen (Tusseau-Vuillemin 2001).

Many enterprises of the food industry are *heavy consumers* of water. For example, 0.5 ton of water is spent in *slaughterhouses* for each killed animal in the course of slaughter and butchering (Furon 1966); 5 ton of water per ton of milk is used at *dairy farms* for washing containers (bags, cans, and bottles); while production of 1 ton of sugar requires 100 ton of water in *sugar mills* (Spangler 1980).

Photo 9.33 Many enterprises of the food industry are heavy consumers of water. For example, 0.5 ton of water is spent in slaughterhouses for each killed animal in the course of slaughter and butchering. A steer restrained for stunning just prior to slaughter is shown here (Photo credit: http://en.wikipedia.org/wiki/Slaughterhouse)

The compositions of pollutants are very different, depending on the specialization of enterprises. So, organic compounds (fats and proteins), mineral suspensions, and chlorides prevail in the waste waters of *meat processing* plants. The discharges of cattle slaughterhouses are polluted the most (Uglov 2006).

The *milk processing* industry is a heavy polluter. A dairy farm processing 100 ton of milk a day discharges in its waste waters the same quantity of organic products as a town with a population of 55,000 people (Siso 1996). For example, a dairy factory near Mosul (Iraq) causes substantial pollution of the Tigris River. The content of phosphates, and biochemical oxygen demand (BOD) and chemical oxygen demand (COD) increase (Khayat 1986).

The waste waters of *margarine* production plants are characterized by high acidity and high contents of fats and sulphates (Willey 2001). A large volume of nitrogen-containing waste forms in the production of *cheese* (Tusseau-Vuillemin 2001). Preparation of 1 kg of cheese yields 9 kg of whey. About a *half* of its global production is not processed, but instead is discharged in the form of waste waters (Siso 1996); in this case, the biological oxygen demand (BOD_5) reaches 3,000 mg/l (Kionga-Kamau 1995).

The *brewing industry* exerts a considerable influence on surface waters. In the production of 1 m^3 of beer, about 4 m^3 of waster waters is formed (Horst 1995). The effects of the waste waters of the brewery works in Mosul (Iraq) are expressed in reduction of

Photo 9.34 Many enterprises of the food industry are sources of heavy water pollution. Hydrobionts suffer to the greatest extent from this pollution. The influences on the organisms are related to reduction in dissolved oxygen in water and to the toxicity of a number of pollutants. Effluents of waste water from a sugar mill in Sudan are shown here (Photo credit: United Nations Environment Programme (UNEP), from *UNEP Sudan Post-Conflict Environmental Assessment* report)

Photo 9.35 The production of smoked products results in serious atmospheric pollution with gases. All types of smoking chambers generate phenols, carbonyl compounds, acids, and benzopyrene. Pork ribs being smoked are shown here (Photo credit: http://en.wikipedia.org/wiki/Smoking_(cooking))

Photo 9.36 A large volume of nitrogen-containing waste forms in the production of cheese. Preparation of 1 kg of cheese yields 9 kg of whey. About a half of this whey is not processed, but instead is discharged in the form of waste waters. Industrial cheese production in Switzerland is shown here (Photo credit: Matthias Kabel)

Photo 9.37 Dust that forms in flour milling plants, sugar mills, and plants producing cocoa powder, dried milk, and other products is able to spontaneously explode. A view of the damage caused to the Imperial Sugar refinery at Port Wentworth, Georgia (United States), is shown here (Photo credit: U.S. Chemical Safety and Hazard Investigation Board)

Photo 9.38 The effects of food production on underground waters are partly related to improper waste storage. For example, during filtering of melt and rain waters at meat-processing industry waste storage facilities, pathogenic microorganisms can enter the underground water horizons. The photo shows an illegal dump of slaughterhouse waste in Sudan (Photo credit: United Nations Environment Programme (UNEP), from *UNEP Sudan Post-Conflict Environmental Assessment* report, 21 June 2007)

dissolved oxygen content and increases in chemical oxygen demand and biochemical oxygen demand in the Tigris River (Khayat 1986). The waste waters of *olive processing plants* are highly toxic due to their content of phenols (D'Anibale et al. 2004).

The influences on *atmospheric air* are related to pollution with dust and different gaseous contaminants. The emissions of *dust* usually originate from dry, loose products (sugar, salt, grain, flour, coffee, tea, starch, etc.). In most cases, the dust particles arise in the course of mechanical fragmentation. The food industry in Russia releases to the atmosphere 1.4% of the total volume of solid particles for all industrial sectors (Yanin 2004b).

Emissions of *odorous gaseous substances* are characteristic of this branch. They may be *visible* (as for instance, in cases of vegetable oil expression, coffee bean roasting, smoking of meat and fish, drying of fish, and broiling of peanuts and hamburgers). Sometimes, the odours are emitted without *visible* pollution. Examples of this category include cooking of tomatoes, processing of spices, and fish dressing and processing (Protection of the atmosphere against industrial pollution 1988, vol 2).

The production of *smoked products* results in quite serious atmospheric pollution with gases. All types of smoking chambers generate phenols, carbonyl compounds, acids, and benzopyrene. Benzopyrene is of great importance because it accounts for 97% of the environmental danger related to the production of smoked products (Kim et al. 2004). The adverse effects of cold smoking processes are greater than those of hot smoking processes (Kim and Filippov 2003).

As for the *animal world*, hydrobionts suffer to the greatest extent from pollution of this industry. The influences on them are related to reduction in dissolved oxygen in water and to the toxicity of a number of pollutants. Examples of these effects include mass fish mortality due to discharges of waste waters from a brewery in Iraq (Khayat 1986) and a sugar mill in Latvia (Sugar plant ordered to close 2005). Another example is the sharp decrease in species diversity of zooperiphyton due to waste waters from a cheese dairy in Russia (Skalskaya 2002).

The condemnation of land is related to the accumulation of considerable amounts of waste in some enterprises. When different *cereals* are processed, huge masses of husks, fine vegetable particles, and other debris are generated (Rudyka et al. 1999). For example, production of *flour* and *rice flour* and *cotton* cleaning result in the formation of 17.7, 66, and 63 ton of waste per worker a year, respectively (Yanin 2004b). In some factories producing potato starch, 100,000–250,000 m^3 of starch-containing sludge is generated every year (Facts and figures: food processing and the environment 1995).

In the making of *baked goods* and *confectionery*, the waste basically consists of reject pastry and eggshells. For example, 34 ton of reject pastry and shells of four million eggs (approximately 28–38 ton/year) are generated in a plant producing 6,000 ton of goods every year (Nayman 2006). Serious problems also arise with respect to *packaging materials*, which constitute a considerable portion of domestic waste (Brown 1993).

The influences on human *health* are basically related to the fact that 80–85% of foreign substances that penetrate the human organism are contained in food (Kim and Kim 2005). The systematic consumption of some products increases the risk of *oncological* diseases. For example, the processes of salinization and smoking, and the use of some spices result in contamination of foodstuffs with oncogenic nitroso compounds (Kim and Kim 2001; Krasnov et al. 2004).

Dust that forms in flour milling plants, sugar mills, and plants producing cocoa powder and dried milk and so on is able to spontaneously explode (Yanin 2004b). For example, dust exploded at a sugar refinery in Port Wentworth, Georgia (United States) on 7 February 2008. As a result, 13 people were killed and 42 were injured (http://en.wikipedia.org/wiki/List_of_industrial_disasters#Food_industry).

During 1958–77, 220 *explosions* with considerable death tolls were recorded in the grain elevators of the United States. For example, on 22 January 1977, 36 people were killed in *Westwego*, Louisiana (United States), and on 27 December 1977, 18 persons were killed in *Galveston*, Texas (United States) (Marshall 1989).

The effects of the food industry on the environment are illustrated by Photos 9.33–9.38.

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10 Mining and Mineral Processing

Abstract

Development of deposits of useful minerals involves a system of organizational-engineering measures for extracting minerals from the Earth's interior. Deposits of commercial minerals are accumulations of mineral substances at the Earth's surface or interior that are suitable for industrial development in their amounts, quality, and mode of occurrence. Mining can be considered to be the oldest branch of human activity, next to agriculture, which is somewhat older. The dependence of early societies on mined products is clearly demonstrated by the names of epochs: Stone Age, Bronze Age, and Iron Age. Deposits of commercial minerals are sharply differentiated in types of mineral raw materials. They include deposits of ore minerals (ferrous and non-ferrous metals) and deposits of rock products, which are divided into deposits of fossil fuels (solid–coals and combustible shale, and liquid–oil and gas) and non-combustible deposits (salts, building materials, etc.). The effects of the mining industry on the environment begin in the course of exploration and appraisal and preparation of the deposit for mining operations, and they continue over the whole period of its development and, not infrequently, for many years after mining operations are discontinued.

10.1 Opencast Mines

Opencast mining is extraction of commercial minerals from the Earth's surface using open-pit workings. Materials typically extracted from opencast mines include metal ores (copper, iron, gold, and molybdenum), coal, diamonds, clay, gravel, marble, limestone, gypsum, granite, gritstone, and coquina (http://en.wikipedia.org/wiki/Open-pit_mining). About 60% of metallic ores, 85% of non-metallic ores, 100% of non-metallics, and about 35% of coal are produced by this method. The distribution of mineral resources of the world is shown in Fig. 10.1.

In the case of opencast mining, the most *significant* operations from an environmental viewpoint are water pumping from the open cast when deposits are dewatered, shooting operations, ore extraction, and storage of 'barren' rock.

Opencast mining is a very powerful source of effects on practically all *components* of the natural environment: (1) condemnation of land; (2) soils; (3) vegetation; (4) animal world; (5) atmospheric air; (6) surface and underground waters; and (7) relief.

From the viewpoint of the *area of condemned land*, the mining industry is among the leading branches of industry. Extraction of 1 million tons of coal disturbs

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Fig. 10.1 Mineral resources of the world (not including fuels) (Kholina et al. 2009. Reproduced with permission of V.N. Kholina)

from 3 to 43 ha; iron ore, from 14 to 640 ha; manganese ore, from 76 to 600 ha; ores for production of mineral fertilizers, from 22 to 97 ha; limestone, from 60 to 120 ha; and phosphorites, from 22 to 77 ha (Pevzner et al. 2001; Mirzekhanova 2003).

In the *United States,* about 1.5 million hectares – that is, 0.16% of the country's territory – was used for mining operations in 1950–1991. Of this area, quarries occupied 59%; opencast spoil banks, 20%; concentrating mill tailing dumps, 13%; mine dumps, 5%, and lands that were unsuitable due to surface subsidence and holes, 3%.

Of all alienated lands, 40% fall on the coal industry, 18% on sand and gravel mining enterprises, 14% on enterprises producing stone materials, 5% on plants for clay production, 5% on copper-producing facilities, 3% on iron ore production, 2% on phosphorite extraction, and 13% on production of other materials (Kulikova 2005).

The *dimensions of dumps* depend strongly on the content of the commercial component. For example, a mining enterprise in Baia Mare (Romania) produces 1.6 ton of gold and 9 ton of silver every year, and in this case, 2.5 million tons of 'tailings' is generated. It is not difficult to calculate that the commercial component is only 0.00042% of the processed rock volume; that is, about 236,000 units of solid waste is produced per unit of final product (Govorushko 2007).

The influences on *soils* are evident in their contamination with fuels and lubricants, flushing liquids, sludge, and other materials. The accumulation of dust from dumps and open casts on the soil surface reduces soil's fertility. During reclamation activities, the physical

Photo 10.1 An opencast operation is a powerful factor in relief transformation. The photo shows the Lebedinsky mining processing plant (Kursk magnetic anomaly**,** Russia). The depth of the open pit is 450 m, and its dimensions are 4 by 5 km. Annually, about 50 million cubic metres of mined rock is carried from the open cast of the plant. There is a linguiform island of rock at the centre of the open cast. It is a dead rock, and this area has been avoided lest the time be expended for its removal (Photo credit: Russian Space Agency, taken at an altitude of 380 km)

properties of soils are disturbed and other impacts occur (Lukanin and Trofimenko 2001).

The natural state of *plant* cover is disturbed both around open casts and in the land plots where production sites are established. These disturbances include destruction of trees and shrubbery, and degradation and loss of grass cover. The effects on vegetation may be indirect and caused by air and soil pollution, which finally have negative effects on plants.

The influences on the *animal world* are also indirect and are caused by contamination of other media. Soil invertebrates are affected to the greatest degree; amphibians and small mammals follow; and birds are affected to a lesser degree. The effects on ichthyofauna are generally caused by increases in the acidity of surface waters, and they often are considerable. Freshwater fish usually do well at pH of 5.0–8.5. A sudden change in pH within this range can have adverse effects on them, when the range expands from 4.0 to 9.5, the fish perish as a rule (Govorushko 2009).

The *basic sources* of air pollution are open casts and grinding-sorting factories (Ovseychuk 2006). *Specific sources* of dust and gas emissions include (1) explosions; (2) motor transport; (3) handling operations; (4) drilling operations; and (5) dust-forming surfaces (dumps, slopes, tailing dumps, etc.).

The *main component* of aerosol atmospheric contamination is mineral dust. In ore quarries, more than 90% of the rock mass is extracted by using drilling and blasting operations. The amounts of dust formed are 0.043–0.254 kg of dust per kilogram of explosive material (Lukanin and Trofimenko 2001).

The *total volume* of dust discharged as a result of opencast mining in the Russian Federation is 460,000

Photo 10.2 As was mentioned for Photo 10.1, an opencast operation is a powerful factor in relief transformation. The mining of each ton of ore is accompanied by several cubic metres of overburden. In this case, a variety of heavy machinery is used: for example, excavators and bulldozers. An excavator at the Pavlovsk coal open cast (Primorsky Krai, Russia) is shown (Photo credit: A.M. Panichev, Pacific Geographical Institute, Vladivostok, Russia, 25 August 2004)

ton a year (Goncharov et al. 2005). As compared with other branches of industry (power engineering, petrochemistry, etc.), the spatial scales of this pollution are not so considerable, which is explained by the relatively large sizes of particles discharged into the atmosphere.

Surface waters are the component of the natural environment that is subjected to geochemical transformation to the greatest extent. Generally, pollutants enter surface waters from three *sources*: (1) dewatering of mine workings; (2) drainage effluent from 'waste' rock dumps; and (3) drainage of concentrating mill tailing dumps (Yanin 2005).

As for contamination, the *sulphide minerals* are of great significance. When deposits are being developed, the rocks are crushed and, as a result, there are large increases in their reactive surface areas. The abrupt increase in accessibility to oxygen results in intensification of the oxidation processes of sulphide minerals and growth in discharges of ore components. From the ore-bearing rocks, considerable quantities of heavy metals, aluminium, iron, manganese, etc., are released, which are also toxic for aquatic organisms (Govorushko 1997).

In Germany, the production of 1 ton of brown coal consumes 5 m^3 of water on average (Kulikova 2005). Dewatering of quarries causes *underground water* levels to drop, forming a depressed funnel area, which may be 2–3 orders of magnitude larger than the area of the quarry. Around the Kursk magnetic anomaly (Russia), drops in levels reach 50–113 m and increase

Photo 10.3 Important sources of air pollution in opencast mining are motor transport and handling operations. The main component of atmospheric contamination is mineral dust. An open cast where phosphorite is mined (south-western Tunisia) is shown (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 23 August 2008)

Photo 10.4 One more source of air pollution in opencast mining is dust-forming surfaces (dumps, slopes, tailing dumps, etc.). The dust kicked up by the wind at a Yankee Doodle tailings pond, Montana (United States) is shown (Photo credit: S. Jennings, Montana State University, United States, September 2000)

Photo 10.5 Dewatering of quarries causes underground water levels to drop, forming a depressed funnel area, which may be 2–3 orders of magnitude (100–1,000 times) larger than the area of the quarry. The open cast of the Homestake Gold Mine in Northern California (United States) is shown. This field was the largest one in the western hemisphere; a total of 40 million ounces (12,444 ton) of gold was produced in it. The field was closed down in December 2001, after 125 years of production (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 19 June 1997)

at rates of 1–3 m per year, while the funnel area is about 40,000 km^2. Around the Donets Basin (Ukraine), it exceeds 100,000 km^2 (Kovalevsky 1994).

An opencast operation is a powerful factor in *relief* transformation. The mining of each ton of ore is accompanied by several cubic metres of overburden. The area of positive topographic forms (dumps) is usually slightly larger than that of negative forms (quarries). In the Mikhailovsky mining and concentration complex (Kursk magnetic anomaly), for example, the area of dumps is 2,000 ha, while that of quarries is only 1,500 ha.

On the whole, opencast operations exert marked adverse effects on the environment; *surface waters* and *ichthyofauna* are among the components that are subjected to the greatest influence.

The effects of opencast operations on the natural environment are illustrated by Photos 10.1–10.6.

Photo 10.6 The natural state of plant cover is disturbed both around open casts and in the land plots where production sites are established. These disturbances include destruction of trees and shrubbery, and degradation and loss of grass cover. The photo shows deforestation at a site where clay is extracted in the Brazilian city of Rio de Janeiro. The hill depicted is Morro da Covanca, in Jacarepaguá (Photo credit: http://en.wikipedia.org/wiki/Land_clearing, 20 May 2009)

10.2 Underground Mines

Underground mining is extraction of minerals from the Earth's interior without disturbance to the Earth's surface. Underground mining accounts for about a *third* of the minerals that are mined in the world. The depths of underground mines are, on average, 200–500 m (Shvetsov et al. 1992). The *deepest* mines in the world are the TauTona (Western Deep Levels) and Savuka gold mines in the Witwatersrand region of the Republic of South Africa, which are currently working at depths exceeding 3,900 m (http://en.wikipedia.org/wiki/Underground_mining_(hard_rock).

Two basic *techniques* are used in underground mining: (1) blast-hole drilling (periodic explosion of the rock, loading and transportation of loose rock, support setting; it is a cyclic technology); and (2) combined techniques, in which the basic technological processes are combined in time (Gorodnichenko and Dmitriyev 2008).

There are more than 100 *underwater mines* that are opened from shorelines. Some of them are about 8 km away from shore at sea depths of up to 120 m. Every year, they provide millions of tons of *black coal* in Japan, Canada, Great Britain, and Turkey. *Iron ore* mining is widely conducted in Japan, Australia, Canada, and Finland. In the Hudson Bay (Canada), *copper-nickel ores* are produced, and *tin* is extracted near the Cornwall Peninsula coast (Great Britain), while, in Turkey, deposits of *mercury ores* near the Aegean Sea shore are developed.

Underground mining exerts impacts on the following natural *components* (Govorushko 1999): (1) surface waters; (2) underground waters; (3) animal world; (4) vegetation; (5) geological environment; (6) condemnation of land; and (7) atmospheric air.

The *major factor* influencing *surface waters* is discharge of contaminated mine drainage waters. In the course of underground coal mining alone, 1.4 billion cubic metres of water is pumped every year from mines. This water is contaminated with suspended substances, including fine particles of coal and rock, colloidal particles, and different bacteria; it is enriched with dissolved chemical substances, and it contains surface-active materials (Protection of the environment against anthropogenic impacts 1993).

Photo 10.7 Longwall mining is a form of underground coal mining in which a long wall of coal is mined in a single slice (typically 1–2 m thick). The longwall panel (the block of coal that is being mined) is typically 3–4 km long and 250–400 m wide. The photo shows longwall mining in Bochum, Germany (Photo credit: http://en.wikipedia.org/wiki/Longwall_mining)

Photo 10.8 The major factor influencing surface waters in underground mining is discharge of contaminated mine drainage waters. The carryover of chemical elements in mine drainage waters continues after a mine has been closed. The photo shows highly contaminated acidic mine drainage coming from an abandoned underground mine in Redding, Shasta County, California (United States) (Photo credit: National Oceanic and Atmospheric Administration, 1992)

Discharged mine drainage waters are often characterized by their *acidity*. For example, a discharge of mine drainage waters in the Donets Basin (Ukraine) having a volume of 55 million cubic metres results in a drop of pH in the watercourses from 7.9 to 3.6. In addition, mineralization doubles, while content of sulphates triples (Gorshkov 2001). In the Republic of South Africa, river waters, not infrequently, contain increased concentrations of *uranium* from drainage waters of gold mines (Winde and Sandham 2004).

Natural run-off from waste and ore dumps is especially great in localities with high amounts of precipitation. The *major pollutant* of these waters is suspended substances.

The carry-over of chemical elements in mine drainage waters continues after a mine has been closed (Semikobyla 2007). For example, hundreds of tons of

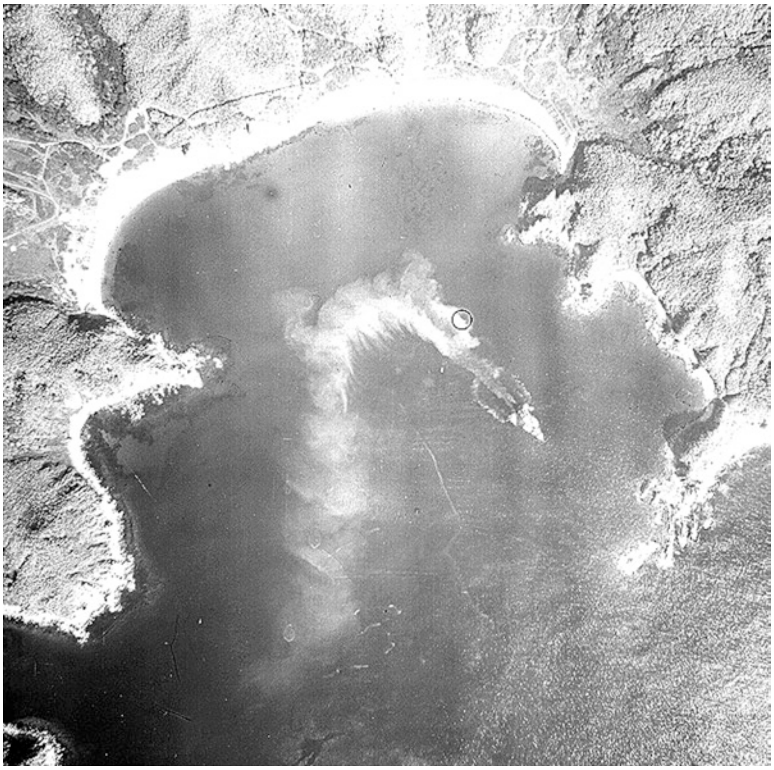

Photo 10.9 In the course of underwater mining, water pollution is inevitable. A plume of polluted water caused by sand extraction from the sea bottom is shown. The sand was extracted for construction of the port of Vostochny in Primorsky Krai, Russia. The photography altitude is 3 km (Photo credit: I.S. Seleznev, 1989 г.)

non-ferrous metals is carried every year by mine waters from an abandoned sulphide deposit complex near Freiberg (Germany); these metals settle partially in the river deposits, while the remainder is carried to the sea (Kulikova 2005).

The effects on *underground waters* are caused by drainage of the water-bearing horizons by mine workings. In the course of water pumping, cones of depression are formed. Their dimensions depend on geological and hydrogeological conditions in the area and the duration of drainage works. Their radii can reach 10 km (Protection of the environment against anthropogenic impacts 1993). Mines not only dehydrate adjacent territories but also contaminate the drained underground waters (Kulikova 2005).

Underground mining requires less *condemnation of land* than opencast mining. Nevertheless, the surface complex of buildings and structures (mine site) occupies considerable land and includes administration buildings, dumps, slime pits, warehouses for the natural drying of slime, coal storage facilities, quarry mine workings, and other facilities (Semikobyla 2007).

The impacts on the *geological environment* consist of formation of underground mined-out space due to extraction of rocks and the minerals they contain. In the course of mining, rock bursts – sudden fracture failure of the strained part of the mineral mass adjacent to the underground mine working – sometimes occur. At most, they are observed in coal mines at working depths of more than 200 m, in ore deposits, and so on.

The following *types of rock bursts* have been identified based on *intensity* (Seismic dangers 2000): (1) bursting – bounce from strongly strained walls of a mass (solid block) of separate pieces of rocks; (2) shocks – formation failures deep in the mass; (3) microshocks – destruction and insignificant rock outbursts into the mine workings, without damage to mine working supports, machines, or mechanisms; and (4) rock bursts proper – outbursts of considerable quantities of rock into the underground mine workings accompanied by destruction of mine working supports and displacement of equipment.

Rock bursts result in complication of the mineral deposits development owing to disturbances of mine working supports, and damage to and moving of

Photo 10.10 As a result of extraction of great volumes of rock, there are gradual subsidence or crush bursts of the overlying rock roof. The image shows the result of the collapse of the Elura lead-zinc underground mine after removal of stope material in New South Wales, Australia (Photo credit: http://en.wikipedia.org/wiki/Underground_mining_(hard_rock), 27 January 2006)

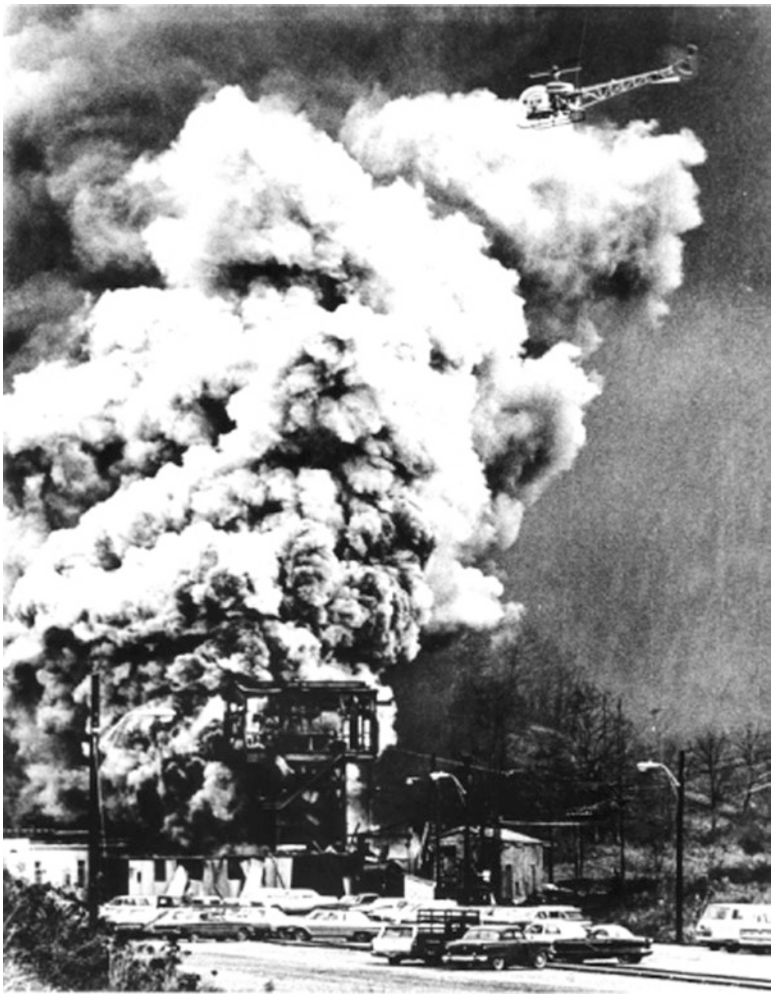

Photo 10.11 Historically, coal mining has been a very dangerous activity, and the list of historical coal mining disasters is a long one. In the United States alone, more than 100,000 coal miners were killed in accidents over the past century, with more than 3,200 dying in 1907 alone. The photo shows fire and smoke pouring from the Consol No. 9 mine in Farmington, West Virginia (United States), following an explosion. The Farmington coal mine disaster killed 78 (Photo credit: http://en.wikipedia.org/wiki/Coal_mining, 20 November 1968)

machines, mechanisms, and equipment. One widely known example of such effects is the most powerful outburst ever recorded, in 1968, in which 14,000 ton of coal and 600,000 m^3 of methane were displaced in the Donets Basin at a depth of 750 m (Yasamanov 2003).

The major sources of *atmospheric* pollution associated with underground mines are the gas-dust emissions. It has been estimated that 27 billion cubic metres of methane, 16.8 billion cubic metres of carbon dioxide, and 200,000 ton of dust are discharged every year into the Earth atmosphere from underground mine workings (Glukhov et al. 1997). Approximately 20–21 billion cubic metres of methane is released from coal mines, while the remaining amount is provided predominantly by mines producing iron, copper, gold, nickel, mercury, diamonds, and potassium salts (Slastunov et al. 2001).

Gases and dust are also released from the surfaces of waste dumps and mineral storage areas. In coal mines, conic dumps or pit refuse heaps are commonly encountered, many of which may *ignite spontaneously*. The burning rock dumps discharge much smoke and harmful gases (Protection of the environment against anthropogenic impacts 1993).

The effects of underground mining operations on the environment are illustrated by Photos 10.7–10.11.

10.3 Drag and Hydraulic Extraction of Deposits

Drag and *hydraulic methods* are used for development of *placer* deposits. Placer deposits form owing to the destruction of *primary* deposits by the processes of weathering and further movement of the matter. The concentrations of the commercial component depend on differences in the densities of the component and surrounding loose sediments. There are many *types* of placers, but two of them are of the greatest importance: (1) river and (2) coastal-marine.

Placer deposits provide gold, platinum, diamonds, optical grade quartz, amber, different accessory minerals (ilmenite, rutile, zircon, and monazite; materials containing titanium, zirconium, and hafnium; and raw materials used for production of thorium and cesium), building materials (gravel, sand), and other materials. The greatest *coastal-marine* placer deposits are within water areas of Australia, India, the United States (Alaska, California), and the Republic of South Africa (Mironenko and Sorokin 2007).

The development of placers is a specific *form of opencast* mining. In the case of *river* placers, *cleaning* the surface of vegetation, *development mining* (removal of the upper non-productive stratum), *watering*, and *production* (extraction of the commercial component from the productive stratum) are necessary. In the course of production, the flushing of sands and their concentration are conducted based on differences in the physical properties of commercial minerals and barren rocks (Leshkov 1977).

Coastal-marine placers are developed in different *ways*. Within inshore belts, sands are extracted by scrapers, bulldozers, excavators, and hydraulic guns. At great depths (up to 160 m), *dredges* equipped with hoist winches and wireline bucket-grapplers are applied. The bucket is dropped into the sea, cut into the ground, and lifted up after the material is captured. There are also dredges with *sludge pumps.*

The *drag* and *hydraulic* development of placers *mainly influences* surface waters and hydrobionts. The condemnation of land is also of great importance. Impacts on underground waters, atmospheric air, soils, vegetation, and terrestrial animals are much less.

The influences of river placer development on the conditions in surface and underground waters are related to the following *factors*: (1) operations are carried out in the overflow lands and valleys of rivers; (2) technology provided for the displacement of watercourse channels, and their blocking by dams and banks, disturbs the natural hydrological regime; and (3) in the course of excavating of rocks with dredges, water is contaminated, and drainage flows contain heavily precipitable mineral particles (Zelinskaya et al. 1999; Konnov 2008).

The *turbidity* of dredge flows is generally 15–20 g/l, which exceeds the natural turbidity by hundreds of times (Degtev 1994; Tereshina 2003). Scour of anthropogenic formations in the flood plain and unimpeded carry-over of materials of this scour to rivers are also of great importance.

The drag development of *coastal-marine* placers also results in considerable contamination of the water. For example, in the course of extraction of building materials from the Baltic Sea bottom, the water turbidity increases from 8 to 400 times (Litvin and Tsupikova 1999).

This much water contamination affects *hydrobionts*. The high concentrations of the suspensions reduce illumination and the productivity of phytoplankton. Fine suspensions that are deposited in river channels deprive fish of their spawning grounds, and they

Photo 10.12 For development of river placers, cleaning the surface of vegetation, development mining (removal of the upper non-productive stratum), watering, and production (extraction of the commercial component from the productive stratum) are necessary. The photo shows the exploitation of alluvial gold deposits in the upper reaches of the Yahsu River, Tajikistan (Photo credit: L.V. Desinov, Institute of Geography, Moscow, Russia, July 1988)

prevent small aquatic fauna from seeking refuge between stones (Pain 1987). In the development of a placer located in the higher part of a small river, the contamination can affect practically the whole downstream part of the watercourse (Potemkin 1995).

In the development of coastal-marine placers, the redeposition of the suspended material constitutes the greatest danger to *fish* spawning on the ground and also to *filtering molluscs*. Some species of fish that are visually searching for food avoid sections with concentrations of suspended substances of more than 10 mg/l. This also influences the nutrition processes of *sea birds*. When mineral extraction is carried out in the vicinity of *spawning grounds*, the latter are entirely destroyed (Litvin and Tsupikova 1999; Kulikova 2005).

The *condemnation of land* is great in the case of river placer development. In the course of extraction of alluvial minerals with the use of dredges, quarries caused by ground extraction, dams, and dredge relief elements – numerous dumps of barren rocks and flushing tailings – are formed (Potemkin 1995; Govorushko 2003a).

Pollution of the *atmosphere* takes place mainly during drilling and blasting operations (crushing of large boulders and fragments of hard rocks, loosening of frozen rocks and ice), as well as due to dust from rock dumps. Some contribution is provided by the construction of hydraulic structures, approach roads, and other structures (Zelinskaya et al. 1999). The effects on *soils* consist of the destruction of the humus layer in the course of construction of structures, blocking with dumps, and contamination of soils with dust.

The effects on *vegetation* are expressed as a cleaning of the placer and mine site surface from trees, bushes, and grass; difficulties in the processes of photosynthesis, growth, and development of plants in adjacent territories result from the pollution of plant leaves with dust.

The effects of dredge development of placers on the environment are illustrated by Photos 10.12 and 10.13.

Photo 10.13 The drag development of placers results in considerable contamination of the water, affecting hydrobionts. The high concentrations of the suspensions reduce illumination and the productivity of phytoplankton. Fine suspensions that are deposited in river channels deprive fish of their spawning grounds, and they prevent small aquatic fauna from seeking refuge between stones. A dragging of a river gold placer in Magadan oblast (Russia) is shown (Photo credit: V.A. Solkin, Pacific Geographical Institute, Vladivostok, Russia, 8 June 2007)

10.4 In Situ and Heap Leaching

Mining operations that use *leaching* started not long ago. The *different types* of leaching are based mainly on selective *dissolution of metals* in their oxidized form. As a result of interactions with reagents, the ores are transformed into freely soluble compounds from which one can easily extract the deposited metals (Myazin and Myazina 2006).

In addition to the different kinds of leaching – chemical, bacterial, electrochemical, and radiochemical – there are also different *process flow sheets* for this method of ore concentration. Heap and in situ leaching are the *most widely used methods* (Wippermann et al. 2005).

Heap leaching and, to a lesser extent, *in situ leaching* are widely used in different *countries* (the United States, Spain, Chile, Czech Republic, Canada, China, Mexico, Peru, Zambia, Australia, Republic of South Africa, and others) for extraction of uranium, copper, gold, and silver. Patented methods for leaching lead, zinc, molybdenum, tungsten, tin, arsenic, bismuth, and other metals are known. The contribution of these methods to the production of *uranium* is the greatest. For example, the Beverley uranium mine in Australia, using in situ leaching, produces about 21% of the world's uranium (www.theoildrum.com/node/3877).

The *technology* of ore processing by the method of *heap leaching* is as follows. The crushed ore is placed on a prepared damp-proof base. Then, the stack of ore is irrigated with leaching solutions that filter through the stack and then enter trays or pipelines. Further along, they are collected in specially equipped reservoirs, where they settle. Afterwards, metal is extracted from the solution (Dementyev et al. 2005; Krylova et al. 2005).

The principle of *in situ leaching* is analogous. The leaching solutions are supplied through wells to the underground ore body; then the solutions, saturated with metal, are pumped out to the surface. Further

Photo 10.14 In the case of heap leaching, the major factor causing adverse environmental influences is leakages that arise when the watertight diaphragms under the ore stacks and in the clearing pools are damaged. The photo shows a cyanide heap-leach at the Zortman-Landusky Mine (Photo credit: S. Jennings, Montana State University, United States, July 1996)

along, the metal is extracted from the solution (Wippermann et al. 2005).

At present, the major method of recovery of metals from ores is *cyanide* leaching. As a reagent, salts of cyanic acid are used – sodium or potassium cyanide with concentrations of 0.02–0.3%, which are characterized by very high toxicity. Thus, the *major environmental problems* are related to the circulation of production solutions.

In the case of *in situ leaching*, it is necessary to provide protection against *penetration of the commercial solutions* into underground waters. A thorough geological examination of the area, especially from the viewpoint of tectonic disturbances, is required. Where faults or fractured zones are present, it is necessary to carry out works with the aim of creating artificial watertight barriers (Lbov et al. 2000). In the case of *heap leaching*, environmental problems are caused by things such as spillages, leakages from pipelines, and incomplete flushing or neutralization (Piskunov et al. 2007).

The major *factors* causing adverse ecological influences are (1) contamination of underground waters with toxic substances used to convert the useful mineral into the mobile state; (2) contamination of surface water bodies by emergency discharges of solutions containing toxic substances; (3) contamination of soils by emergency discharges of toxic substances; and (4) contamination of the atmosphere by emissions of gases through sublimation, gasification, and melting (Ovseychuk 2006).

Underground waters are the most vulnerable natural component because existing technologies do not fully prevent losses of cyanide-containing processing media. In the case of *in situ leaching*, they may penetrate into the fresh water-bearing horizons. In the case of *heap*

Photo 10.15 During in situ leaching, the leaching solutions are supplied through wells to the underground ore body; then the solutions, saturated with metal, are pumped out to the surface. Further along, the metal is extracted from the solution. Major environmental problems are related to the circulation of production solutions that are extremely toxic. The photo shows uranium production in the Czech Republic (Straz deposit) (Photo credit: http://en.wikipedia.org/wiki/File:Ralsko_uran.jpg, 24 March 2007)

leaching, leakages arise when the watertight diaphragms under the ore stacks and in the clearing pools are damaged (Piskunov et al. 2007).

When the method of *in situ leaching* is used, underground waters are contaminated due to leakage of casing strings. For example, for uranium production in the Czech Republic (Straz deposit), 16,000 wells were drilled in 1967–2000. Through them, 4.1 million tons of sulphuric acid, 315,000 ton of nitric acid, 26,000 ton of hydrofluoric acid, 1,400 ton of hydrochloric acid, and 112,000 ton of ammonia were pumped. This resulted in great contamination of the neighbouring water-bearing horizon (Kopecky and Slezak 2002; Datel and Ekert 2008).

Impacts of heap leaching units on *surface water bodies* are possible when surface run-off from the industrial site occurs as a result of emergency situations, as well as when water from contaminated underground sources reaches the surface waters (Robertus et al. 2005).

In the operation of heap leaching units, *soils* and snow cover may be contaminated by ore dust that is released in the course of crushing and transporting of ore and as a result of wind erosion of the ore stake surface. In summer, the surface migration of mobile forms of technogeneous substances and their accumulation in soils are possible (Piskunov et al. 2007).

The *major sources* of *air pollution* are crushing-and-sorting plants, ore stakes, and hydrometallurgical shops. Among the *major contaminants* are hydrocyanic acid vapours, nitric oxides, and free chlorine (Petrov 2005). In addition, *noise pollution* extends for 3–7 km from the heap leaching units (Petrov et al. 2006).

The effects of in situ and heap leaching operations on the environment are illustrated by Photos 10.14 and 10.15.

10.5 Land Oil and Gas Development

Oil production started in 1850 in the state of Pennsylvania (United States) (Kondratyev et al. 2003). At present, its *volume* reaches approximately 3.5 billion tons a year (Vavilova 2003).

By now, more than 600 oil- and gas-bearing basins have been explored, and 450 of them have been developed, while the total number of oil fields is estimated at 35,000. In 1994, there were 923,557 oil wells in the

Photo 10.16 The oil contamination of soils is especially high in cases of oil spills from wells. Soil contamination causes loss of humus, and degradation of the hydrophysical, chemical, and ion-exchange properties of the soils and their biological activity. Soil contamination around oil wells in the north of West Siberia, Russia, is shown (Photo credit: I. Gavrilov, 20 November 2003)

world, and the average yield for a well was 9.2 ton per day (Mirzekhanova 2003).

The *production rates* of oil wells in different regions differ markedly. *High rates* of oil ingress are particularly characteristic of the wells of Norway (735 ton per day) and Great Britain (350). The production rates of oil wells are characterized by *moderate values* in Libya (187), Malaysia (160), and Egypt (118). The yield for wells is *quite low* in India (28) and Indonesia (26) and *very small* in Russia (7.4). The *smallest average yield* (1.6 ton per day) is noted for wells in the United States, except for the oil fields of Alaska (Khaustov and Redina 2006; Smekalov 2006).

Land oil extraction affects the following environmental *components* and parameters (Govorushko 2003b): (1) surface waters; (2) underground waters; (3) soils; (4) vegetation; (5) animal world; (6) atmospheric air; (7) land withdrawal; (8) geologic environment; and (9) radiation background.

Oil extraction exerts the greatest effect on *surface waters*. The major *sources* of contamination are spent drilling fluids and grouting mortars, as well as the associated waters. Drilling waste waters, when they enter a water body, change the water transparency, colour, and odour, while the chemical reagents present in them bind the dissolved oxygen (Novikov et al. 1995).

Land oil production affects the rivers in northern regions to a greater extent, which occurs for the following *reasons* (Telegin et al. 1988): (1) disrupted oxygen balance as a result of biochemical oil oxidation; (2) increase in duration of the adverse influences of oil products due to low rates of biochemical oxidation at low temperatures; and (3) concentration of fish resources within small non-freezing sections of rivers (wintering basins).

The effects on *underground waters* result from the following *processes*: (1) cross-flows between the water-bearing horizons due to the low-quality cemen-

Photo 10.17 One more source of oil contamination is drilling sludge. Bore mud is an aqueous suspension of particles, including products of rock destruction in borehole bottoms and walls, and products of drilling assembly and pipe casing abrasion by clay minerals. As a rule, bore mud is stored in pits. Due to frequent disturbance of hydraulic seals, soils are contaminated with toxic salts and oil products. The photo shows a storehouse for drilling sludge near Nogliki, Sakhalin Island, Russia (Photo credit: V. Kantor, Greenpeace Russia, 1999)

tation and leakage of casing strings; (2) filtration of oil and mineralized waters from the ponds (pits); (3) filtration from well embankments; and (4) injection of water, air, or gas into the oil reservoirs (Dorozhukova and Yanin 2002).

The effects, on the whole, are expressed as changes in *hydrogeological conditions*, such as the following: intensification of water exchange; formation of new water-bearing horizons; mixing of waters; changes in levels, slopes, rates of motion, and the chemical and gas composition of underground waters; changes in temperatures; and drops in the intrastriatal pressures (Moskovichenko et al. 2008). On completion of oil production, cross-flows often arise between the fresh and salt horizons or between the water-bearing and oil-bearing horizons (Keselman and Glaz 1983).

The major *factors* affecting *soils* are (1) drilled-out rocks; (2) drilling sludge; and (3) oil. At a well depth of 2,500 m, 350 m^3 of ground is extracted to the surface, while at a depth of 5,000 m, 800 m^3 is extracted. These rocks are usually stored in the form of dumps near the wells. In view of their strong contamination with drilling mud and oil products, the effects on the soils are considerable, and are expressed as loss of humus, and degradation of the hydrophysical, chemical, and ion-exchange properties of the soils and of their biological activity (Dorozhukova and Yanin 2002; Utkina et al. 2005). Arctic, tundra, and marsh peat soils differ in that they have the lowest resistance to contamination with carbohydrates (Gennadiyev 2009).

Bore mud is an aqueous suspension of particles, including products of rock destruction in borehole bottoms and walls, and products of drilling assembly and pipe casing abrasion by clay minerals. As a rule, bore mud is stored in pits. Due to frequent disturbance of hydraulic seals, soils are contaminated with toxic salts and oil products. According to data presented by N.P. Solntseva and co-authors (2003), the effect of pits in the west Siberian taiga is found at distances of more than 300 m.

Photo 10.18 Direct influences of oil production on vegetation occur in two ways: (1) disturbances of physiological processes due to conformal coating of surfaces of trunks and leaves and (2) poisoning of plants with toxic oil components. Generally, the plants perish and revegetation begins after 2–3 years. Destruction of trees due to direct contact with oil near Nizhnevartovsk (West Siberia, Russia) is shown here (Photo credit: M. Lodewijkx, Greenpeace International, August 1999)

Oil pollution of soils is greatest in cases of emergency oil spills from wells. Soil contamination results in changes in its microelemental composition, and water-air and oxidation-reduction regimes. The resulting excess of organic carboniferous substances disturbs the normal ratio of carbon and nitrogen as well as results in oxygen deficit (Yakovlev 1987).

Direct influences on *vegetation* occur in two *ways* (Korobov 2004): (1) disturbances of physiological processes due to conformal coating of surfaces of trunks and leaves and (2) poisoning of plants with toxic oil components. Generally, the plants perish, and revegetation begins after 2–3 years. In the surviving specimens, changes in the rhythm of development, including omission of some phenological stages; their general suppression; and occurrence of necroses and tumours are characteristic (Dorozhukova and Yanin 2002).

Indirect impacts are mainly evident in contamination of soils and atmospheric air. In the case of *intrasoil oil contamination,* there are destruction of the grass cover, changes in its species composition, and suppression of the growth of trees. The influence of *atmospheric pollution* is expressed through changes in the chemical composition of air and thermal contamination.

The effects on the *animal world* are generally evident in the changes in other natural components: soils, vegetation, and surface waters. Destruction of vegetation in the course of construction works affects invertebrates to a greater extent, as the vegetation cover is a major habitat. First of all, the numbers of arthropods decrease.

The *sources* of *atmospheric* pollution are gases released in the course of well drilling and testing. Associated petroleum gases also play a major role. In west Siberia alone, about 19 billion cubic metres of associated gases are burned, which results in air pollution with combustion products such as polyaromatic hydrocarbons, carbon and nitrogen oxides, and some heavy metals. As a rule, the resulting pollution extends for tens and even hundreds of kilometres from the source of the emissions (Polishchuk et al. 2001).

Mercury is nearly always present in the associated petroleum gases, predominantly in the atomic form

Photo 10.19 The sources of atmospheric pollution in oil drilling are gases released in the course of well drilling and testing. Associated petroleum gases also play a major role. In West Siberia alone, about 19 billion cubic metres of associated gases are burned, which results in air pollution with combustion products such as polyaromatic hydrocarbons, carbon and nitrogen oxides, and some heavy metals. The photo shows burning of associated petroleum gases near Neftejugansk (West Siberia, Russia) (Photo credit: M. Lodewijkx, Greenpeace International, August 1999)

(Ozerova and Pikovsky 1982). During the development of oil fields, mercury is present in the atmosphere. The extent of pollution depends on the mercury content in gases, which varies within the limits of 0.01–14,000 $\mu g/m^3$. In some hydrocarbon deposits, mercury reserves are comparable with those in mercury deposits proper (Ryzhov et al. 2000).

The scales of *land* withdrawal are also great. During prospecting and oil production, a territory is occupied by structures such as wells, processing containers, reservoirs, treatment facilities, oil-gathering stations, oil treatment plants, group pumping stations, and oil transfer pumping stations (Panov et al. 1986).

The impact on the *geological environment* is significant. It is evident in Earth surface deformations and increases in seismicity. The surface subsidence in the oil and gas area in Long Beach, near Los Angeles, California (United States), can serve as an example of *deformations*. The oil production there started in 1928. By 1955, 148 million tons of oil had been extracted

Photo 10.20 Land oil and gas development is a dangerous activity. Fires and explosions are not infrequent events. The photo shows an oil well fire burning near Taji, Iraq, in March 2006 (Photo credit: http://en.wikipedia.org/wiki/Oil_well_fire)

from sandstone with a total thickness of 300 m, and the surface level had dropped by 6.6 m during this period. Throughout the period of production, the drop in the surface level reached 8.8 m (Kazansky et al. 1992).

The intensification of *seismicity* is related to oil recovery, which results in changes in the stressed state of rock. As a rule, earthquakes arise 15 and more years after the beginning of field development. Among the examples of increased levels of moderate seismicity are the Romashkino and Novo-Elkhovo fields in Tatarstan. During the period 1986–1989, 160 local earthquakes were recorded there, and the magnitude of some of them reached 6.0 (Nikolayev and Vereshchagina 2006).

The delivery to the Earth surface of matter from large depths is often accompanied by increases in *background radiation*. In some cases, they may be significant. For example, examination of a number of oil fields in the Khanty-Mansi Autonomous Area (Russia) showed that acceptable doses of gamma radiation were exceeded 38 times in the eastern part of the area and 48 times in the western part (Romanyuk et al. 2002). In this region, 4% of fields are characterized by anomalous emissions of radionuclides (Bulatov 2004).

The effects of land oil production on the environment are illustrated by Photos 10.16–10.20.

10.6 Sea Bottom Oil and Gas Development

The *first offshore oil well* was drilled in March 1938, at 2.4 km from the shore in the state of Louisiana (United States) (Mitina and Singh 2005).

There is a steady increase in sea bottom oil production volumes. Offshore oil and gas exploration are

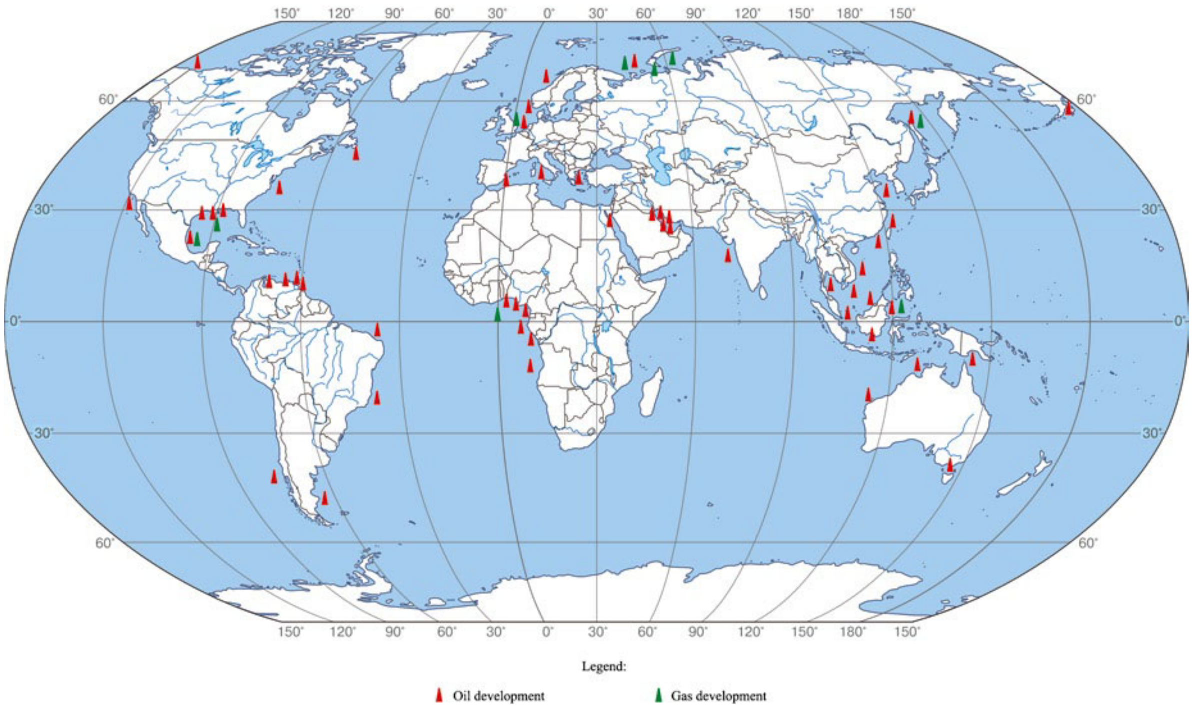

Fig. 10.2 Region of oil and gas development in the world ocean (Maksakovsky 2006, vol 1. Reproduced with permission of V.P. Maksakovsky)

carried out by more than 100 of 140 countries having access to the sea. More than 2,000 oil and gas fields have been discovered, and 700 of them have been developed (Novikov 1999). About 6,500 operating oil and gas platforms located on the continental shelves of 53 countries exist throughout the world (Mitina and Singh 2005). Regions of oil and gas development in the world ocean are shown in Fig. 10.2. At present, exploration and appraisal are carried out at depths of up to 800 m and at distances of 200–500 km from the shore (Rodionova and Bunakova 1999). It is believed that about 70% of oil resources are concentrated on continental shelves (Mironenko and Sorokin 2007).

Four *stages* have been identified in the development of oil-and-gas fields (Patin 1997): (1) geologo-geophysical exploration; (2) preparation and construction of field facilities; (3) field exploitation; and (4) completion and liquidation.

The major kinds of activities at the *first* stage are *seismic exploration works*, which interfere with fishing and affect aquatic organisms, and exploration drilling (which disturbs underwater landscapes, leads to condemnation of water areas, pollutes the water due to process water disposal, and pollutes the air with atmospheric emissions).

At the *second* stage, drilling *platforms* are erected, *pipelines* are laid, and onshore processing facilities are constructed. The major effects are disruption of the physical environment, discharge of liquid and solid wastes, and the creation of barriers to fishing.

At the *third* stage, drilling, working, and transport operations are performed. These activities are accompanied by such effects as technological discharges in the course of drilling and extraction, emergency spills and emissions, condemnation of water areas, and barriers to fishing.

At the *fourth* stage, the platforms and pipelines are disassembled, the wells are capped, and other activities take place. In this case, barriers to fishing and other users, condemnation of water areas, and pollution due to discharges arise (Patin 1997, 2004).

The *adverse environmental consequences* are generally related to drilling and emergency oil spills.

Photo 10.21 During the first stage of oil-and-gas development, geologo-geophysical exploration is conducted. This activity includes seismic exploration, which interferes with fishing and affects aquatic organisms, and exploration drilling (which disturbs underwater landscapes, leads to condemnation of water areas, pollutes the water due to process water disposal, and pollutes the air with atmospheric emissions). The photo shows oil drilling in the ocean (Photo credit: Charles Meertens, University Corporation for Atmospheric Research, USA)

The impacts of *drilling* on the aquatic environment are associated with two *processes*: (1) drainage to the sea of waste mud and (2) release from the well of drilling deposits. The *used drilling mud* is generally discharged directly to the platform foundation. The depths of most wells vary between 900 m and 5,000 m. In the course of drilling a well, the drilling mud is changed, on average, 8–10 times, and 160,000–340,000 l are usually changed at a time (Mitina and Singh 2005).

The *solid phase* of the drilling mud forms mudflows or is in the water in the form of a suspension. The turbidity concentration in the flow decreases rapidly with distance from the well. For example, when drilling mud is discharged in a volume of 39,750 l at a rate of 729 l/min, the dilution of the suspended fraction to background level occurs at 500 m from the platform. The quantity of discharged macro-particles depends on their concentrations in the drilling fluid (Korobov 2004).

From one platform situated in the Gulf of Mexico (50 km south of Galveston, Texas, United States), 207 kg of fine solid particles are discharged at a depth of 21 m. On the whole, the dilution of the soluble fraction occurs more slowly. The drilled sediments are discharged under pressure from the well to heights of 1 m and more and are spread by currents (Mitina and Singh 2005).

The *distance* the disintegrated particles travel depends on their sizes and the rates of the bottom currents. For example, the distance fine sand (0.1–0.25 mm) travels at a current rate of 30 cm per second is only 57.4 m, whereas, coarse and medium pelite (particle sizes are 0.001–0.01 mm) travels 37.5 km (Matishov and Denisov 1998).

On completion of drilling, the major source of influence of operating platforms is the *associated waters*. These waters are characterized by high temperatures,

Photo 10.22 Accidents at oil-producing offshore platforms provide the greatest contribution to the pollution of seawater. As a result of the accident on 3 June 1979 at the drilling rig *Ixtoc-1* (Campeche Bay, south-eastern Mexico coast), the daily oil blowout reached 4,000 ton at the beginning. The numerous attempts to plug the well only decreased the ingress of oil into the sea. The oil blowout continued until 24 March 1980 (i.e. it lasted for nearly 9 months), when the well head was plugged with 30 ton of concrete block. The total leakage of oil reached 500,000 ton (Photo credit: National Oceanic and Atmospheric Administration, June 1979)

low oxygen content, and considerable mineralization (up to 35,000 mg/l, caused by inorganic cations of sodium, magnesium, and potassium, and anions of chloride, sulphate, carbonate, and bicarbonate), as well as carbohydrates and other organic components (in parts-per-million concentrations) (Kochergin et al. 2000).

The *volumes* of the associated water discharges vary depending on time and geological formation. For example, the above-mentioned platform in the Gulf of Mexico oil field supplies, on average, 160,000–223,000 l of associated water a day, and these waters contain 382 g of alkanes and 17–23 g of light aromatic hydrocarbons – predominantly, benzene, toluene, and ethylbenzene (Mitina and Singh 2005).

Under conditions of drilling and normal operation of oil wells, of *prime environmental importance* are hydrocarbons contained in the associated waters. Although they are released in insignificant volumes from one well on a daily basis, their total quantities over a long period of time are more than sizeable.

In 1983, for example, 65% of production wells in the North Sea discharged 18,000 ton of oil into the water (Dixon 1987); thus, a total of 27,700 ton of oil was released into the sea. According to different estimates, from 102,000 to 153,000 ton of oil entered the waters of the North Sea in 1985 (Bedbourgh et al. 1987). In the course of field development, the specific weight of the formation waters in the total volume of the fluid extracted increases. So, 3 m^3 of formation water is extracted per cubic metre of oil on occasion in the United States (Keselman and Glaz 1983).

Waste mud also contains oil; however, concentrations are insignificant. In 1981, the operational discharges of oil in the composition of oil-containing

Photo 10.23 A second famous accident in the Gulf of Mexico began on 20 April 2010, at a well situated 64 km to the south-east of the Louisiana coast. As a result of an explosion, 11 persons were killed and 17 were wounded. Fire then engulfed the platform. After burning for approximately 36 h, the *Deepwater Horizon* sank on the morning of 22 April 2010 (Photo credit: http://en.wikipedia.org/wiki/Oil_spill)

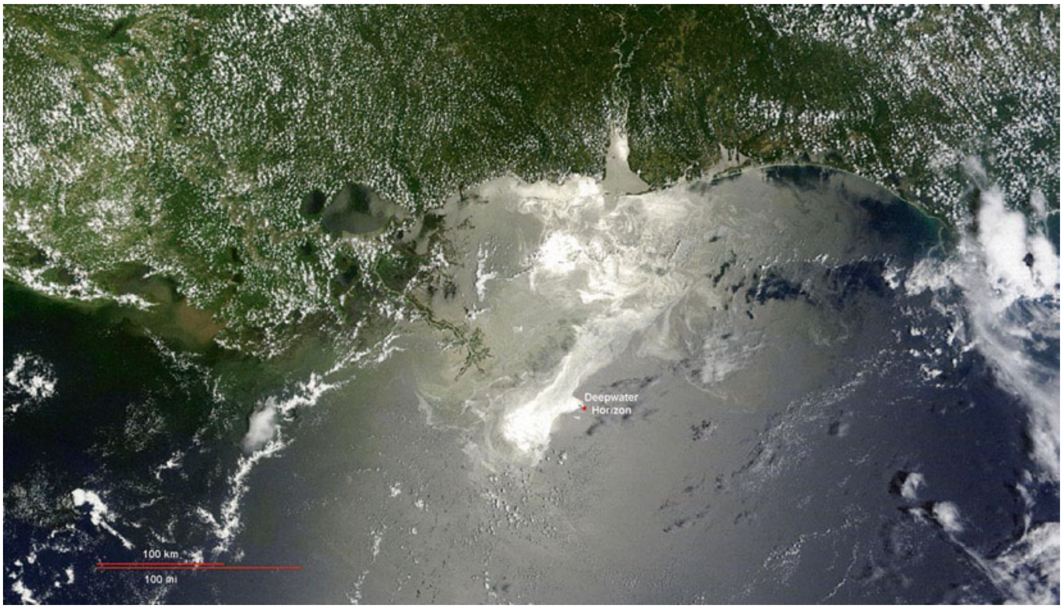

Photo 10.24 This image shows oil spreading north-east from the leaking *Deepwater Horizon* well in the Gulf of Mexico. The oil appears as a maze of silvery-grey ribbons in this photo-like image. The location of the leaking well is marked with a red dot. On 15 July 2010, the leak was stopped by capping the gushing well head, after it had released about 4.9 million barrels (780,000 cubic metres) of crude oil (Photo credit: http://en.wikipedia.org/wiki/Deepwater_Horizon_oil_spill)

waste mud reached 76 ton, while in 1985, it was 93 ton (Bedbourgh et al. 1987). On the whole, the discharge of waste mud does not result in serious consequences (Patin 2004).

The *greatest contribution* to the pollution of sea water is made by *accidents* at oil-producing offshore platforms. Two of them that happened in the Gulf of Mexico are well known. For example, as a result of the accident on 3 June 1979, at the drilling rig *Ixtoc-1* (Campeche Bay, south-eastern Mexico coast), the daily oil blowout reached 4,000 ton at the beginning. The numerous attempts to plug the well only decreased the ingress of oil into the sea. The oil blowout continued until 24 March 1980 (i.e. it lasted for nearly 9 months), when the well head was plugged with 30 ton of concrete block. The *total leakage* of oil reached 500,000 ton (Oil spill case histories 1967–1991 1992).

The *second* accident began on 20 April 2010, at a well situated 64 km to the south-east of the Louisiana coast. As a result of an explosion, 11 persons were killed and 17 were wounded. On 15 July 2010, the leak was stopped by capping the gushing well head after releasing about 4.9 million barrels (780,000 m^3) of crude oil (http://en.wikipedia.org/wiki/Deepwater_Horizon_oil_spill).

On the whole, oil extraction from the sea bottom makes an important contribution to the pollution of water bodies. It is believed that its share is 7.5% of total oil pollution (Vladimirov and Izmalkov 2000), while losses correspond to 1% of the oil extracted (Dolotov 1996).

The pollution of surface waters adversely affects *hydrobionts and sea birds*. The description of this effect is given in Sect. 12.5, Water transport.

Accidents at oil-producing platforms result in *loss of life*. Over the period 1970–1983, 725 accidents were recorded, including 536 at floating drilling units and 189 at marine stationary platforms (Stolyarova and Karpova 2000). Over the period 1970–1995, more than 1,200 people were killed in offshore oil fields (Hart 2000). Among the *most damaging accidents* is the Piper Alpha accident on the offshore platform *Piper Alpha*, which was located in the British sector of the North Sea oil field in July 1987; 167 lives were lost (Collinson 1999). Another is an accident at the mobile platform *Ocean Ranger*, which sank in Canadian waters on 15 February 1982 in the Grand Banks area near Newfoundland island; this accident took 84 lives (Hart 2000).

The effects of offshore oil and gas production on the environment are illustrated by Photos 10.21–10.24.

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http://en.wikipedia.org/wiki/Deepwater_Horizon_oil_spill
http://en.wikipedia.org/wiki/Open-pit_mining
http://en.wikipedia.org/wiki/Underground_mining_(hard_rock)
www.theoildrum.com/node/3877

11 Agriculture and Forestry

Abstract

Agriculture and forest management are two closely related fields. Their similarity can be found both in their aims (to a greater or lesser degree, they are oriented on food provision for the population and raw materials supply for different industries) and in their basic operating principles (based on the growth of living organisms in the process of their development). This similarity can be seen the best when plant growing is compared to forest management. In both cases, practically identical methods of growing, enhancement and increase of productivity, using fertilizers, and protection from weeds (herbicides) and pests (pesticides) are used. The differences lay primarily in the duration of the production cycle: half a year for crop farming, 3–5 years for horticulture, but not less than 10 years for forestry. Besides, the object of agriculture greatly depends on human involvement. For many countries and international organizations (e.g., Food and Agriculture Organization of the United Nations), forestry is a part of the agricultural sector.

11.1 Agriculture

Agriculture is the production, processing, marketing, and use of foods, fibres, and by-products from plant crops and animals. The share of agriculture in the gross domestic product (percent) for various countries is shown in Fig. 11.1.

11.1.1 Plant Growing

Plant growing is a branch of agriculture that deals with the cultivation of domestic plants. Agricultural land occupies 15.32 million square kilometres, which comprises 11% of the terrain on Earth (Modern global changes 2006, vol 2). On average, there is 0.4 ha of *agricultural land* per capita. These numbers are the largest in Kazakhstan – 2.0, Canada – 1.6, and Argentina – 0.9 ha per capita, and they are the smallest in China – 0.09, Egypt – 0.05, and Japan – 0.04 ha per capita (Vavilova 2003). Cultivated land percentage of total land area is illustrated in Fig. 11.2.

Plant growing produces 88% of all food supplies (Modern global changes 2006, vol 2). The most *important cultivated plants* are (million tons a year, harvest of 2007): corn, 792; rice, 659; and wheat, 606 (http://en.wikipedia.org/wiki/Cereal). Another essential culture is the potato, and in comparison to the first three cultures, its production rate is considerably smaller: 315 million tons in 2006 (http://en.wikipedia.org/wiki/Potatoes).

There are three main *factors* of the plant growing impact on the environment: (1) agricultural equipment; (2) land reclamation; and (3) agricultural chemicals.

In the sphere of plant growing, *agricultural equipment* is used for cultivation, harvesting, and processing of domestic plants. The diversity of the equipment

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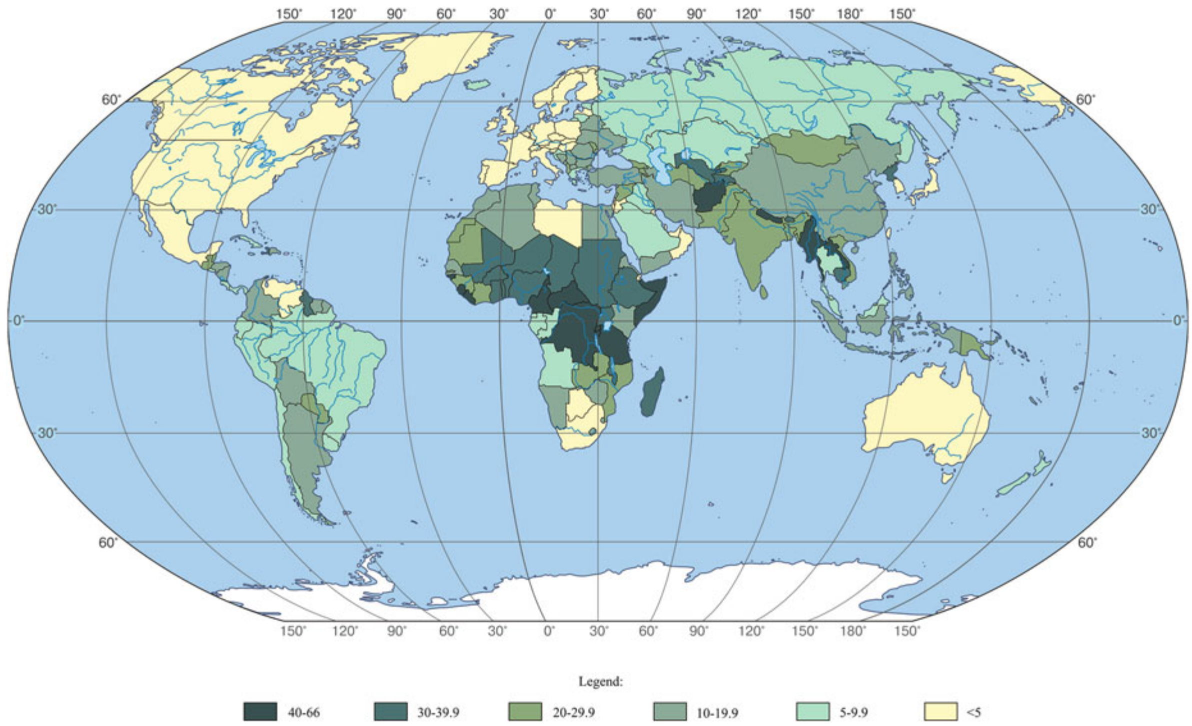

Fig. 11.1 The share of agriculture in GDP (percent) (Kholina et al. 2009. Reproduced with permission of V.N. Kholina)

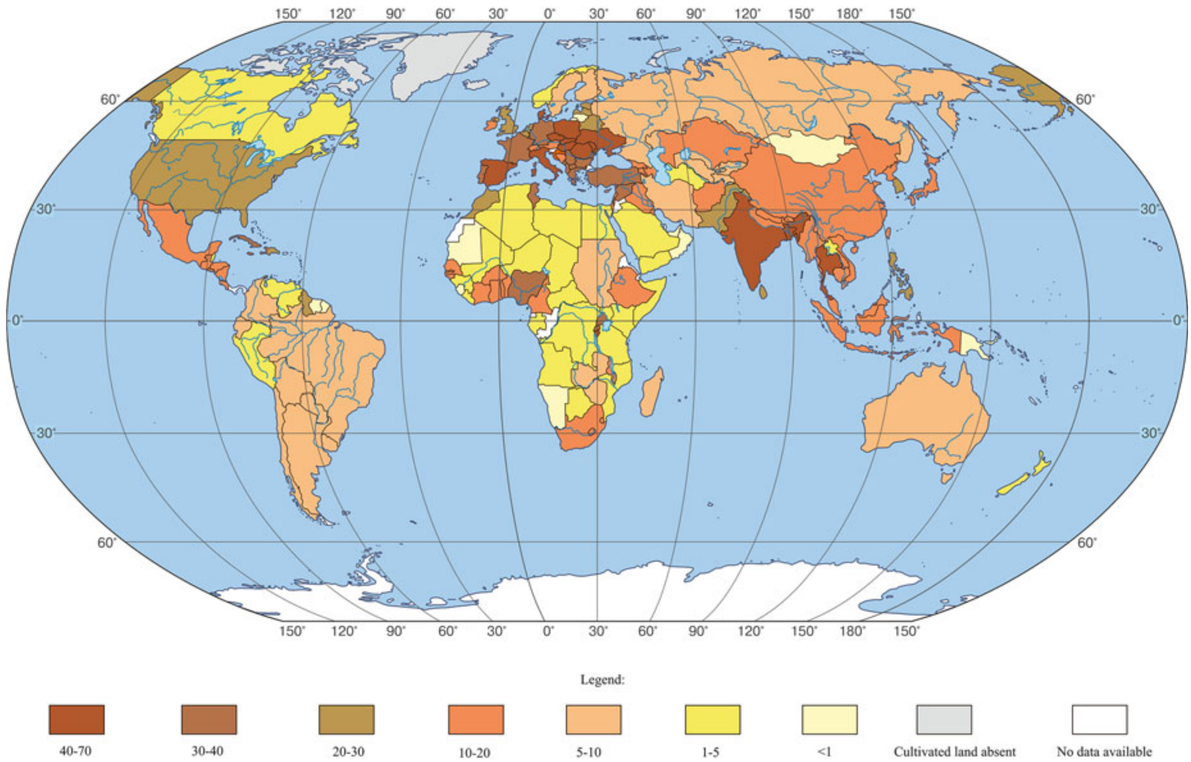

Fig. 11.2 Cultivated land percentage of total land area, 1992 (Resources and Environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of Science)

Photo 11.1 Since ancient times, increases in arable area occur at the expense of territory occupied by forests. The photo shows land cleared for Jhum, a type of shifting cultivation practised in north-east India. This photo was taken at Gandhigram in the Vijaynagar circle of Arunachal Pradesh, India (Photo credit: http://en.wikipedia.org/wiki/File:Jhum.jpg)

used is huge. It can be self-powered or trail-type. Often, it has very heavy gears and powerful combustion engines.

The impacts of agricultural equipment on the natural environment include the *following*: soil *consolidation*; structural *distortion* of soil due to tillage; extermination of soil-forming *microorganisms* and different *invertebrates* (earthworms); *process losses* and *contamination* of soil, water, and air by fuel, lubricant materials, and by-products of running engines; and the *deaths* of animals and birds.

The most environmentally important impact is *soil degradation* due to contact with *machinery*. The ground is affected by the drive systems and operating parts of the agricultural equipment. By the end of fieldwork, only 10–15% of the agricultural land is not affected. The rest of the territory is exposed to the drive systems not less than three to five times.

Due to *ruptures* in the sleeves and pipes of agricultural equipment, 500,000 ton of fluids get into soil in Russia, which takes 2,000 ha of fields out of crop production every year (Afanasyev et al. 2005).

Process losses mean transportation of soil outside the fields. For example, in Turkey, when sugar beets are harvested, permanent soil losses are 1.2 million tons a year (Oztas et al. 2002).

Land reclamation is divided into *drainage* and *irrigation*. On Earth, 157 million hectares of the terrain has been drained, most of it in North America and Central America (56 million hectares). Possible *consequences* of drainage are increases of erosion by wind and water, shallowing of rivers and lakes, risk of floods, a drop in precipitation quantity, declines in animal and fish numbers, vanishing of rare plant species, and depletion of flora. The irrigation aspect of land reclamation is considered in Sect. 13.4 ‘Water transfers’.

Agricultural *chemicals* used include mineral *fertilizers* and chemical plant *protectors*. During the 2006–07 season, 164 million tons of fertilizer was used, of which, 98 million tons was for nitrogen, 27 million tons for potassium, and 39 million tons for phosphates. China is the world’s largest mineral fertilizer consumer, using 49 million tons, followed by India (22 million tons), the United States (21 million tons),

Photo 11.2 Sometimes, the effects of plant growing on relief are significant. Where agricultural lands are scarce, it is necessary at times to grow crops on unproductive areas. In the photo, a terraced slope used for growing rice in the Philippines is shown (Photo credit: H.J. Walker, Louisiana State University, 8 February 1985)

Photo 11.3 One of the impacts of plant growing on the environment is methane emissions. Methane is produced on flooded rice fields during partial organic decay under conditions of oxygen shortage. Methane releases from all the world's rice bays are estimated to be 20–100 million tons a year. The photo shows planting of rice in Polonnaruwa, Sri Lanka (Photo credit: UNESCO, Horst Wagner, 1998)

Photo 11.4 In order to prevent pest invasions, pesticides are used. During plane spraying, 20–35% of the total amount introduced gets into the atmosphere, and then into soil and water. Pesticide use is most dangerous for water ecosystems, soils, animals, and also humans due to their high biological reactivity, long duration in the environment, and accumulation potential. The photo shows pesticide spraying in California (United States) (Photo credit: Charles O'Rear, U.S. Department of Agriculture)

Brazil (9 million tons), Indonesia (3.5 million tons), and France (3.4 million tons) (http://www.goodplanet.info/goodplanet/index.php/eng/Food-Agriculture/Fertilizers/Engrais-agricoles/(theme)/263).

The most dangerous of these chemicals are *nitrogen fertilizers*, due to the considerable mobility of the nitrate nitrogen. The most critical impact is the pollution of surface and ground waters by *bound nitrogen*. Not less than a half of surface water pollution by bound nitrogen is due to agriculture. Water contamination by biogenic elements results in excessive algal blooms, which die off and are decayed by anaerobic bacteria. That process leads to *suffocation* of fish and other aquatic animals due to the lack of oxygen.

Phosphate fertilizers are less hazardous. Nevertheless, considerable amounts of phosphates get into water as a result of erosion by water, which also leads to water eutrophication. One kilogram of phosphorus coming from the fields initiates the growth of 100 kg of phytoplankton, which decreases the amount of dissolved oxygen and reduces water quality (Ecological sketches of nature and humans 1988).

Photo 11.5 The most environmentally important impact of plant growing is due to contact of soils with machinery. The ground is affected by the drive systems and operating parts of the agricultural equipment. By the end of fieldwork, only 10–15% of the agricultural land is not affected. The rest of the territory is exposed to the drive systems not fewer than three to five times. The picture shows a CLAAS Lexion combine unloading grain to a chaser bin pulled by a tractor in Germany (Photo credit: http://en.wikipedia.org/wiki/Chaser_bin, 27 August 2010)

A *particular feature* of phosphate fertilizers is that their use in large amounts leads to undesirable accumulations of other *elements* in soil (stable strontium, fluorine, natural radioactive uranium compounds, radium, and thorium are present in phosphate fertilizers). Thus, 2–3 g of cadmium is introduced into soil with the application of 70 kg of superphosphate (Heinrich and Hergt 2003).

The *third main element* of mineral fertilizers (potassium) does not impact the environment much. However, along with potassium, a lot of *chlorine* is brought in, which might lead to adverse effects.

The total production of *chemical plant protectors* (to prevent diseases and pest invasions) is five million tons (Dyakonov and Anoshko 1995), and their global use, on average, is 300 g/ha. In the United States and Western Europe, this number is 2–3 kg/ha. In the form of aerosols, pesticides can be carried over a distance of 500 km (Heinrich and Hergt 2003). Pesticides are dangerous due to their high biological reactivity, long duration in the environment, and accumulation potential.

Depending on the *way* they are used, the following shares of pesticides (of the total amount introduced) get into the atmosphere (Savenko 1991): introduction into furrows, 1–8%; and plane spraying, 20–35%. Of the pesticides applied, 99.9% does not reach the target objects and gets into soil, air, and water (Hart and Pimentel 2002).

Pesticide use is most dangerous for water ecosystems, soils, animals, and also humans. For example, in the former USSR, around 40% of hares, hogs, and elk, more than 77% of ducks, geese, and upland fowl, and more than 30% of freshwater fish that died were *poisoned* by pesticides (Mavrischev 2000).

Pesticide intoxication kills 220,000 people (Palmborg 2002) and damages the health of another three million annually (Cornell 2003). The *causes of intoxication* are given in detail in an article by A. Ferrer and R. Cabral (1995). Though developing countries in Asia, Africa, and Latin America account for only 25% of the pesticides used, 99% of the deaths take place there (Ngowi et al. 2006).

Apart from the three main *factors* of plant growing impact on the environment, there is also the problem of *methane emissions*. Methane is produced on flooded rice fields during partial organic decay under conditions of oxygen shortage (Rudsky and Sturman 2006). Methane release from all the world's rice bays is estimated to be 20–100 million tons a year (Modern global changes 2006, vol 1). The *factors* that determine the quantity of methane produced are the soil type, rice variety, temperatures, and growing method (Kwun et al. 2003).

Withdrawal of nutrients from the fields during harvesting has some importance. For example, a yield of corn of 7 ton per hectare takes out 104 kg of nitrogen, 19 kg of phosphorus, and 22 kg of potassium per hectare (Agricultural ecosystems 1987). Grain crops and potatoes exhaust the soil the most. For a global wheat gross yield of one billion tons, 33 million tons of nitrogen is taken out of the soil (Kazansky et al. 1992).

Plant growing also contributes considerably to *soil erosion*. Annual soil outflow from agricultural fields into water in the United States is estimated to be more than one billion tons. The Mississippi River alone carries out 331 million tons of topsoil into the Gulf of Mexico annually (Ruhl 2000).

The impact of plant growing on the environment is illustrated by Photos 11.1–11.5.

11.1.2 Animal Husbandry

Animal husbandry is the breeding of farm animals. This branch of agriculture provides food products (meat, dairy products, eggs, honey, etc.), raw materials for light industry (leather, wool, silk, etc.), drugs (hormones, serum), some fodders (e.g., bone flour), organic fertilizers, and live drawing force (horses, oxen, mules, deer, camels, etc.). Global livestock density is illustrated in Fig. 11.3.

The main branch of animal husbandry is *cattle breeding* or stock rearing. It supplies one-third of all meat produced globally and almost all the milk. The world's cattle stock is 1.3 billion. Their numbers (million animals) are the highest in India (278), Brazil (208), China (141), the United States (96.7), and Argentina (50.8) (Russia and countries of the world 2008).

Pig breeding, due to the shorter period of reproduction, has a higher growth rate than cattle breeding. This branch of animal husbandry provides 40% of the global meat supply and a sizable amount of rawhide. The leaders in the pig breeding industry (million animals) are China (470), United States (56), Brazil (37), Federal Republic of Germany (24), Poland (18), Vietnam (18), and Spain (18) (Maksakovsky 2006, vol 1).

Sheep breeding is developed the most in (million animals, 2006) China (174), Australia (100), India (63.6), Iran (52.2), Sudan (49.8), and New Zealand (40.1). Leaders in *poultry farming* are (million animals, 2006) China (5,362), United States (2,319), Indonesia (1,401), Brazil (1,019), and India (524) (Russia and countries of the world 2008). Animal husbandry provides 10% of all the food supplies in the world (Modern global changes 2006, vol 2).

11.1.2.1 Stall Feed

Due to stall feeding, the concentration of animals at a location increases sharply, making a stock breeding complex a point source of environmental impact. The main *factors* in this impact are dumping of raw animal materials (excrement and liquid waste), pressed soilage juice, and haying.

The natural *components* that are most affected include the atmosphere, surface and ground water, soil cover, and vegetation. Fish and other aquatic organisms, as well as animals consuming the food grown on soils that are fertilized with raw animal materials, can be *affected secondarily*.

The main environmental problem is the *waste* of animal husbandry; the amount of waste is tremendous. For instance, in Russia alone, poultry farms annually produce more than 200 million tons of poultry manure and two billion cubic metres of wastewater (Khazan et al. 2005).

The impact of animal husbandry waste mainly manifests itself as *atmospheric pollution*. Cattle yards and manure storage facilities emit 136 different gases and odorous substances (Hartung 1992). Some of them affect air locally (e.g., ammonia), and others (carbon dioxide, methane, ozone, nitrous oxide) are greenhouse gases and contribute to global warming. Domestic animals account for 5–10% of global climate change (Tisdell 1998).

Fifty percent of the *ammonia* from fresh manure is lost in the first 24 h. In Great Britain alone, ammonia production equals (Savenko 1991) (in tons a year): on pig farms, 41,000; on poultry farms, 81,000; and on cattle farms, 233,000. In western regions of North Carolina (United States), in 1995, 81,000 ton was

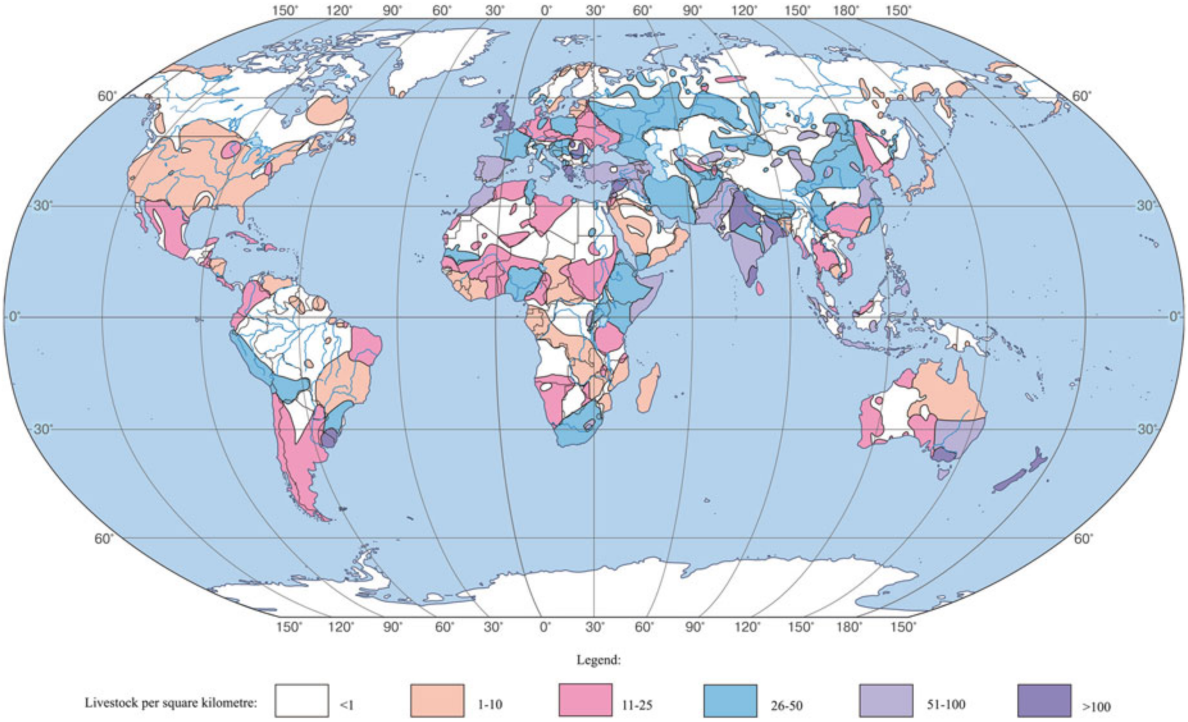

Fig. 11.3 Global livestock density (http://earthtrends.wri.org/text/agriculture-food/map-245.html. Reproduced with permission of World Resources Institute)

emitted, 73% of it from pig farms (Ruhl 2000). Ammonia impacts soil (when ammonia is emitted, soil loses nitrogen) and depresses foliage. The amount of ammonia produced depends on the food, age, and conditions where the animals are kept.

The manure input into *methane* production is not so great; the most important is the role of intestinal fermentation in ruminants. For example, in South and Southeast Asia in 2000, 29.9 million tons of methane was emitted into the atmosphere; of that, the share of manure in methane release was only four million tons, while the source of the remaining 29.5 million tons was digestive fermentation. The greatest amount of methane produced from digestive fermentation is in the Ganges delta (Yamaji et al. 2003).

In many regions, animal husbandry is the *main source* of methane emissions. For example, in Mexico, the total amount of methane produced is 1.89 million tons. Of that, 1.85 million tons is produced at cattle farms (Gonzalez and Ruiz-Suarez 1995).

Nitrous oxide is the most reactive greenhouse gas. It is produced mainly by manure, and this type of emission is 7% of all anthropogenic gases released. Nitrogen oxide contributes to acid precipitation. All domestic animals produce *carbon dioxide* (Tisdell 1998).

Stall feed is an active polluter of *surface waters*. Manure off-flow contains high levels of biogenic matter, helminths, and pathogenic microorganisms. When it all gets into the water, it leads to eutrophication, decreases in dissolved oxygen, and sharp drops in water quality (Denisov and Semizhon 2008).

Among all *fauna*, *hydrobionts* are affected the most. They are impacted through surface water contamination. If an accident occurs, mass mortality can result. For example, in North Carolina (United States), a spill of 96,000 ton of manure waste from a pig farming complex in 1995 led to the death of ten million fish and made mollusc harvesting impossible on almost 147,000 ha of maritime territory (Ruhl 2000).

Photo 11.6 Due to stall feed, the concentration of animals at a location increases sharply, making a stock breeding complex a point source of environmental impact. A commercial chicken meat production house in Florida (United States) is shown here (Photo credit: Larry Rana, U.S. Department of Agriculture)

Photo 11.7 Ensilage harvesting and storage influence groundwater. Some of the products (beet tops, corn, etc.) are kept in concrete pits or bunkers (with special tanks for collecting liquor). Insufficient isolation of these facilities or absence of liquor tanks (which happens often) results in juice leakage. The photo shows an MB Trac rolling a silage heap, or 'clamp', in Victoria, Australia (Photo credit: http://en.wikipedia.org/wiki/Silage)

Photo 11.8 There are two environmental impacts of haying: (1) impacts on terrestrial animals that take place during forage procurement (when agricultural equipment is used on fields to make hay, many wild animals are killed or injured) and (2) depauperation of flora due to the full withdrawal of some plant species. The photo shows cut hay in Israel (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 11 July 2010)

Photo 11.9 The impacts of animal husbandry waste mainly manifest as atmospheric pollution. Cattle yards and manure storage facilities emit 136 different gases and odorous substances. Some of them affect air locally (e.g., ammonia), and others (carbon dioxide, methane, ozone, nitrous oxide) are greenhouse gases and contribute to global warming. A pig farm in Lyons, Georgia (United States), is shown here (Photo credit: Jeff Vanuga, U.S. Department of Agriculture Natural Resources Conservation Service, 2002)

Photo 11.10 One of the sources of soil contamination is burial of dead diseased animals. A channelling of rainwater results in contamination of groundwater with pathogenic microorganisms, which can subsequently lead to contagion of animals and people. The photo shows improper disposal of dead chickens on a south-western Missouri (United States) poultry farm (Photo credit: Charlie Rahm, U.S. Department of Agriculture Natural Resources Conservation Service)

Impacts on *terrestrial animals* take place during forage procurement. For instance, in Germany, where agricultural equipment is used on fields to make hay, many wild animals are killed or injured, primarily roe deer juveniles. The total number of animals that suffers due to this activity is 420,000 (Heiko and Gerold 2002).

Stall feed affects *vegetation* through weed dissemination. There are two million weed seeds in 1 ton of manure. When manure is applied to fields as fertilizer, a significant number of the seeds sprout (Gruzdev 1988). Some importance must be given to fibrous feed *harvesting* on natural grasslands (haying). It sometimes leads to depauperation of flora due to the full withdrawal of some plant species.

When used correctly, raw animal materials have positive effects on *soils*. Concentrations of biogenic elements (carbon, nitrogen, phosphorus, calcium, potassium) in soil increase, as well as the soil's biological activity, harvests, and quality of plants (carotene, protein). Nevertheless, excessive use of animal waste (manure, watering with wastewaters) often leads to increases in nitrate nitrogen concentrations in soil, and that degrades its physicochemical properties.

Excess nitrate nitrogen also leads to the growth of nitrophilous plants, producing huge biomass, mainly weeds (Czerwinski et al. 1987). Further filtration contaminates *groundwater* with water-soluble salts, nitrates, and pathogenic microorganisms, infecting animals and people with brucellosis, encephalitis, gastroenteritis, and other diseases (Nastea and Dumitru 1986).

Impacts on groundwater also happen during *ensilage* harvesting and storage. Some of the products (beet tops, corn, etc.) are kept in concrete pits or bunkers (with special tanks for collecting liquor). Insufficient isolation of these facilities or absence of liquor tanks (which happens often) results in juice leakage. In 1973, in the territory of the modern Czech Republic, 25% of ensilage liquid was released into the soil (Evaluation of economy effect on nature 1985).

The impact of stall feed on the environment is illustrated by Photos 11.6–11.10.

Photo 11.11 Grassland farming is a form of land use that makes it possible to increase food production with minimum costs and, at the same time, maintain ecosystem productivity. Introduction of manure into soil conserves the soil fertility and physical properties. The photo shows manure in Benton, Arkansas (United States) (Photo credit: Jeff Vanuga, U.S. Department of Agriculture Natural Resources Conservation Service, 2002)

11.1.2.2 Livestock Grazing

Livestock grazing is widespread. Permanent pastures occupy 20% of the terrain; apart from that, 24.5% of the land is used occasionally for grazing and 6.7% is tundra deer pastures. There are two *categories* of pastures: (1) cultivated (do not differ much from agricultural lands – the same technology of cultivation, chemicals, and sometimes irrigation is used) and (2) natural, usually with unregulated grazing (Rudsky and Sturman 2006).

The impact of livestock grazing is distributed pretty *evenly* all over an area (apart from the watering points and animal routes). Australia has the *greatest* density of pastures. They *also cover large areas* in the land fund of Latin America, Africa, and Asia. The *total number* of grazing animals is three billion (Gorshkov 1992).

Livestock grazing is a form of land use that allows increasing production at minimal costs; it supports ecosystem productivity. Introduction of manure into the soil improves physical properties and conserves *fertility*. Some *seeds sprout* faster or can sprout at all only after being digested. Grazing and the condition of pastures are closely connected; both insufficient grazing and overgrazing degrade the productivity of an area (Humprey and Patterson 2000; Taddese et al. 2002).

The main *factor* having environmental impacts is *overgrazing*. This occurs when the livestock density per area unit is very high; in this case, the number and the breed of the animals can exceed a pasture's food production capacity. Different plant communities can be used as pastures (steppe, forest, tundra, desert, and semi-desert).

Livestock grazing *impacts* vegetation, soils, fauna, and geomorphology. The impacts of grazing on *vegetation* are diverse and the most serious. The *consequences* of these influences are: (1) vegetation destruction; (2) change in plant species composition; (3) plant community successions; (4) favourable conditions for the spread of plant diseases; (5) decrease of timber quality; and (6) drop in timber growth speed (Govorushko 1999).

The *destruction* of plants occurs in different ways. Animal husbandry often results in the *logging* of forests. In Brazil, for example, 38% of the forests destroyed by logging between 1966 and 1975 were cleared for animal husbandry operations (Newman 1989).

Overgrazing also results in vegetation loss. There are *many places* where overgrazing by goats has caused forest depletion: Greece, Cyprus, south of Madagascar, and some regions of Venezuela. For instance, in 1936, angora goats were brought to the southern part of Madagascar. In a year, there were a thousand animals,

Photo 11.12 The impacts of grazing on vegetation are diverse and are the most serious. The consequences include (1) vegetation destruction; (2) changes in plant species composition; (3) plant community successions; (4) creation of favourable conditions for the spread of plant diseases; (5) decreases in timber quality; and (6) stunting of timber growth. The photo shows grazed (left) and ungrazed (right) woodlots in Minnesota (United States) (Photo credit: Minnesota Department of Natural Resources Archive, Minnesota Department of Natural Resources, Bugwood.org)

Photo 11.13 Among all domesticated animals, goats are the most harmful to the environment. Unlike other animals, goats pull out whole plants when they graze. They are omnivorous, which is their distinctive trait. Owing to their pantophagy, these animals feed even on the bark of trees and bushes. The photo shows damage to trees due to domestic goats in Blue Ridge, South Carolina (United States) (Photo credit: Randy Cyr, Greentree, Bugwood.org)

Photo 11.14 The main factor in livestock grazing having environmental impacts is overgrazing. This occurs when the livestock density per unit area is very high; in this case, the number and the breed of the animals can exceed a pasture's food production capacity. The photo shows the pasturage of sheep (western Tunisia) (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 20 August 2008)

and by 1950, there were more than 250,000. By that time, southern regions of the island had turned into desert (Semenova-Tyan-Shanskaya 1986).

The fact that animals prefer some plants over others leads to *changes in plant species composition*. The plants they prefer are suppressed, and the plants they neglect thrive (Riklefs 1979).

Plant community successions happen fairly often. For instance, during intensive grazing, a *meadow* can turn into *bushes*. Natural forest restoration is becoming problematic in forest pastures. Stoll shoots of broadleaf species are more resistant than self-seeding coniferous sprouts. Due to this, coniferous plants are being replaced with deciduous plants (Anuchin 1991).

Morbidity of plants increases as a result of root damage by hooves, which creates favourable conditions for *fungal infections*, and bark gnawing leads to *trunk rot*.

Deterioration of wood *quality* is connected with nibbling of the tops of sprouting trees, which provokes the growth of *curved trunks*, while bark gnawing results in *trunk scars*. The *slowest growth* is observed in forest stands with shallow roots, such as in spruce forests and coppice oak woods; comparatively high growth rates are found in pine forests and birch wood (Rudsky and Sturman 2006).

Among all domesticated animals, *goats* are the *most* harmful to the environment. Other animals that have adverse effects on the environment include pigs, sheep, and cattle (Spurr and Barnes 1984). Unlike other animals, goats pull out whole plants when they graze. A distinctive trait of goats is that they graze on a very wide range of plant species. They eat even the bark of trees and bushes. It is not unusual to see goats 'grazing' on trees in the mountains of Greece, Turkey and Iran (Suprunenko 1999).

The impacts on *soils* are also diverse. Grazing results in soil *consolidation*. For example, the surface of the bottom of domestic sheep hooves is 50 cm^2 . Taking into account that the mass of one animal is 50 kg, the pressure of its hooves is 1 kg/m^2 (for instance, static pressure of a tank is not more than 0.5 kg/m^2). Passing 10 km a day, a sheep leaves behind 40,000 trails, with a total area of 200 m^2 (Mordkovich 1982).

Soil compaction leads to a decline in *water infiltration capacity* and increases in *run-off* (Meules et al. 2001). Breaking of the surface destroys capillaries, which is followed by changes in the evaporation regime. As a result, the land dries out and deflation occurs (Environmental assessment 1994). Because of vegetation loss, *heating* of the soil increases, which leads to increased evaporation, consolidation of saline liquids, and soil salinization (Modern global changes 2006, vol 2).

Livestock grazing is one of the main reasons for *soil degradation*, accounting for an estimated 35% (Grinevich et al. 1995). A typical *example of overgrazing* is given by F. Ramade (1981): In 1960, the number of sheep in Iran was 66 million, while the limit of the pastures was 26 million.

At present, the *intensity* of livestock grazing has reached catastrophic proportions. For this reason, in *Argentina* and *Chile*, more than 100 million hectares of the land is out of use (Nikolaikin et al. 2003). In India, 250 million feral ‘sacred’ cows have caused huge losses of vegetation in the Himalayan foothills (Rudsky and Sturman 2006). This problem is also acute in tropical regions of *Africa*.

The *animal world* is influenced through the spread of *epizootic diseases*. For example, the rinderpest virus, brought to Serengeti National Park (in the north of Tanzania), resulted in the death of more than 80% of ungulates (buffalo, gnu, etc.), which, in its turn, reflected on predator numbers (Mitchell 2001).

During cattle grazing in forests, undergrowth thinning leads to a drop in the number of *birds*. The drop is also a result of *anxiety*, destruction of nests, and the killing of chickens by shepherd dogs (Anuchin 1991).

The main influence on *geomorphology* is the activation of erosion by water. As a result, animal routes often turn into scour channels, which often become gullies (Mwendera et al. 1997).

The impact of livestock grazing on the environment is demonstrated by the Photos 11.11–11.14.

11.2 Forestry

11.2.1 Timber Processing

Timber processing is the harvesting of wood for economic needs. In 1994, 3.36 billion cubic metres of timber was logged. A bit more than a half of it was used as fuel, and 90% of this fuel was used by the developed counties. Another part (1.47 billion cubic metres) – round wood timber – was mainly used for production of different products, such as sawn timber (0.4 billion cubic metres), chipboard (0.18 billion cubic metres), and fibre for paper (270 billion tons) (Gorshkov 2001).

Forest *resources* of the world (standing volume) are equivalent to 340–370 billion cubic metres, and the area of the forest suitable for exploitation is 25–28 million square kilometres. Global distribution of timber resources is shown in Fig. 11.4. The *countries* with the greatest forest area include Russia (8.1 million square kilometres), Brazil (3.2 million square kilometres), Canada (2.6 million square kilometres), and the United States (2.0 million square kilometres); nevertheless, the *leaders* in timber processing are the United States, Canada, Brazil, and China (Vavilova 2003).

The *science of forest growing*, used to achieve certain previously defined characteristics of quality and quantity, is called *forest management*. To attain those aims, a forester will assign certain actions that he believes will lead to the intended effect. These actions include different *types* of logging and improvement of growing conditions – burnings, fertilizers, and breaking up of soil and forest litter. Measures for forest restoration are also undertaken, which are considered in the following subsection (Berryman 1990).

There are several *types* of logging, such as *forest clearing* (aimed at removal of undesired trees and creation of favourable conditions for the main tree species) and *sanitary logging* (aimed at preventing the spread of diseases and pest multiplication; usually sick or damaged trees are cut). Harvest cutting is targeted at yielding timber and the creation of favourable conditions for forest restoration (Novikov 1999).

Timber processing includes three *phases*: (1) logging operations (logging, branch cutting, cutting area cleaning, timber bucking, dragging, loading of logs on transport); (2) timber transportation (use of logger roads, which connect with railroads, highways, or floatable rivers); and (3) work on industrial log depot/

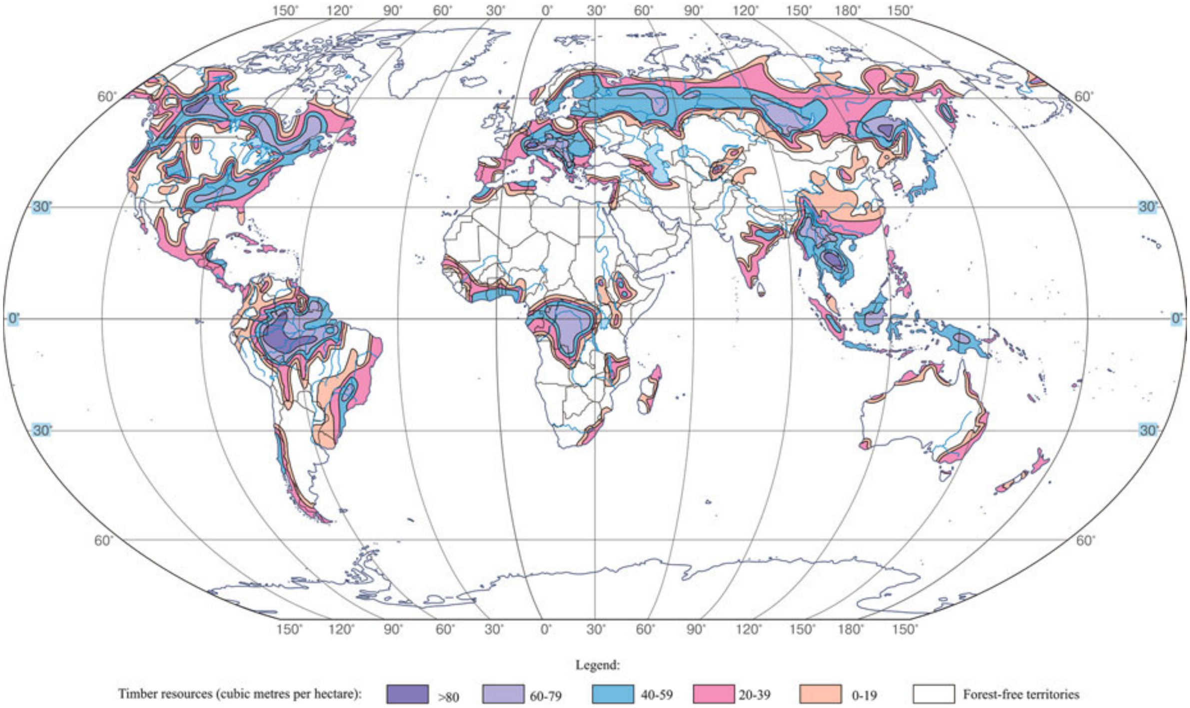

Fig 11.4 Global distribution of timber resources (Resources and environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of Sciences)

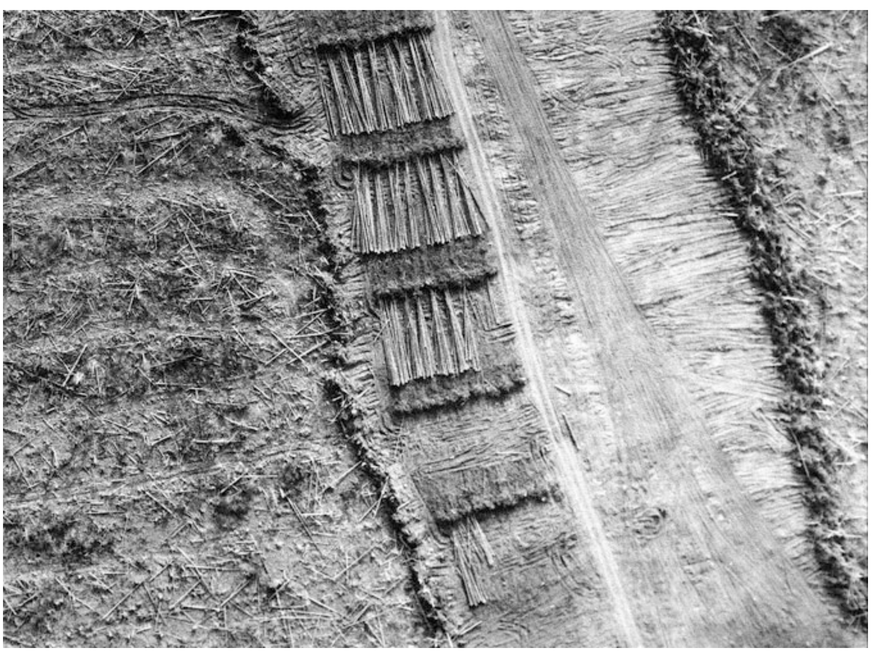

Photo 11.15 Timber processing is the harvesting of wood for economic needs. When a sensible approach is used, the effects on the environment are minimal. However, the use of felled timber is often irrational. Forestry operations near the Svetlaya settlement (Primorsky Krai, Russia), are shown. At the centre of the photo, stored timber destined for further processing is shown, while at the left are rejected trees (Photo credit: I.S. Seleznev, 1990)

Photo 11.16 The first stage of timber processing is logging operations. They include logging, branch cutting, cutting area cleaning, timber bucking, dragging, and loading of logs on transport. The photo shows harvester operations in Karelia (north-western Russia) (Photo credit: V. Kantor, Greenpeace Russia, 13 June 2006)

manufacturing sites of the timber processing industry, where primary conversion of raw material is done and from where timber is shipped (Shelgunov et al. 1989).

Tree cutting means cutting the tree off the root and pushing it in the direction needed. Different equipment is used for full automation of the process. This equipment can be single-processing (only cutting) or multitask (e.g., feller-forwarder, feller-buncher, etc.). Wood transportation is the process of wood and stem harvesting and their transportation to the loggers' road. For this operation, tractors, windlasses, and feller-forwarders are used (Nabatov 1997).

The impacts of timber processing on the environment can be divided into three *categories*: (1) taking matter out of nature (logging and transportation of the wood; sweeping off the soil on some areas, including further washout); (2) introduction of alien substances and energy (such as toxic chemicals for pest control, fuels and combustion products released during timber dragging and transportation); and (3) transformation and redistribution of the matter in nature: changes in forest landscapes due to logging and cleaning out of debris-strewn forest (Geoecological principles of designing of natural-engineering geosystems 1987).

Taking matter out of nature (trunks, branches, leaves) leads to soil *impoverishment* and *decreased productivity*. In Russian forests, trunks comprise 65% of the total timber mass; stumps and roots comprise 13%; bark, 9%; branches and lops, 8.5%; and leaves and needles, 4.5%. In the low latitudes, the share of trunk timber is lower. For instance, in the rainforest of the Ivory Coast, trunks and large branches account for only 64% of the biomass (Gorshkov 2001).

If only trunks are removed, and bark and branches are left behind, then the amount of nutrients from rock weathering, as well as wind-borne nutrients, is enough to cover the losses. Although if leaf and branch litter is also taken, *fertilizers* are necessary. Their application is aimed at activating soil organisms, speeding up the decay of litter and humus, and slowing down soil acidification (Environment 1999, vol 2).

Timber processing influences the following natural *components*: (1) vegetation; (2) soils; (3) animals; (4) surface waters; and (5) atmosphere. In addition, it is not uncommon for this activity to cause human death.

Photo 11.17 The second stage of timber processing is timber transportation. Logger roads or narrow-gauge railways are used, which connect with railroads, highways, or floatable rivers. The picture shows a narrow-gauge railway in Vologda oblast (north-western Russia) (Photo credit: V. Kantor, Greenpeace Russia, 5 September 2006)

Impact on *vegetation* is mainly defined by undergrowth conservation. In tropical forests, selective cutting of the most valuable tree species often takes place. The transportation of one of these trees causes the death or serious damage of another two trees (Golubev 1999). In the developed countries, the damage is much smaller. For instance, during timber processing in south-western France, 30% of the area remains untouched, 32% is covered by the remains of cutting, 29% is changed insignificantly, and only 9% is seriously damaged (Deconchat 2001).

It is believed that harvest cutting disturbs vegetation *diversity* more than gradual felling and selective cutting (Tatarinov 2002). It is also recognized that felling is much safer in winter than during the warm seasons (Bock and Van Rees 2002; Kovalev 2004).

The impacts on *soils* are as follows: (1) fertility decline; (2) soil erosion; and (3) change in physical qualities.

Fertility decline is explained by the fact that most of the biogenic matter is stored in trees and is removed when trees are logged. After logging, the soils are exposed to direct sun rays and strong rains. Deficits of phosphorus and potassium are observed in soils of the humid tropics, and deficit of nitrogen is found in the dry tropics (Golubev 1999). Also, the carbon–nitrogen balance, pH, and concentration of exchangeable bases change (Schmidt et al. 1996).

Erosion of soils is provoked by topsoil disturbance during wood transportation. Intensity of the wash-off during the first couple of years after logging on slopes of 10–20° reaches hundreds of cubic metres per hectare. Main losses of soils occur within the first 5–6 years (Litvin 2002).

Disturbances of *physical qualities* of soil are seen mainly in changes in its density, porosity, and coefficient of filtration (Rosnovsky 1999). Research in Washington state (United States) has shown that soil consolidation as a result of a motor vehicle slipping decreases its filtration characteristics by 92%; microscopic capillaries shrink by 53%, and density increases by 35% (Spurr and Barnes 1984).

Impacts on *animals* are determined by the complexity of ecosystem connections, when a little change can lead to unpredictable results. For example, so-called keystone species play unique, sometimes unclear roles in ecosystems. Logging of such species sometimes leads to catastrophic consequences for fauna (Golubev 1999). Also, hunting and fishing, including poaching, increase in areas where logging is taking place.

Effects on *surface waters* are manifested through increases in seasonal flood levels of rivers and lack of water during other seasons (Geoecological principles of designing of natural-engineering geosystems 1987). The *atmosphere* is polluted by the exhaust of working machinery (Semenov 2001).

Human deaths are connected with accidents, and intoxication caused by chemicals used for pest control. Almost all the cases of poisoning are connected with organophosphate insecticides (Berryman 1990).

The influences of timber processing on the environment are illustrated by the Photos 11.15–11.18.

Photo 11.18 Erosion of soils is provoked by topsoil disturbance during wood transportation. Intensity of the wash-off during the first couple of years after logging on slopes of 10–20 degrees reaches hundreds of cubic metres per hectare. Main losses of soils occur within the first 5–6 years. The erosion development on a logging site in the upper reaches of the Maksimovka River (Primorsky Krai, Russia) is shown (Photo credit: A.M. Panichev, Pacific Geographical Institute, Vladivostok, Russia, 15 June 2005)

11.2.1.1 Timber Rafting

Timber rafting means transportation of wood by water using timber buoyancy. The popularity of this type of activity is *falling*, but in some countries, its importance is still high. For example, in the former USSR, the total length of rafting routes on small rivers alone was 150,000 km (Gorshkov 2001). In the 1980s, more than 40% of timber harvested was transported by water (Shelgunov et al. 1989).

There are *three types* of timber rafting: (1) drift floating (detached logs float with the current); (2) rafting (timber is transported in rafts, mainly with the help of towing vessels); and (3) bag boom towing (detached logs are transported by a vessel in special floating booms) (Ecological encyclopaedia 1999).

Drift floating is used on unnavigable rivers. In the former USSR, in 1988, drift floating was practised on 197 rivers with a total length of 22,900 km (Fomintsev et al. 1990), and 40% of all timber transportation by water was done this way (Shelgunov et al. 1989).

Rafting is used on navigable rivers with the use of the energy of flowing water and the propulsive force of towing vessels. Depending on conditions on the river and the power of the vessel, the volumes that rafts carry can be from 150 to 40,000 m^3, and transportation distance can reach 2,500 km (Shelgunov et al. 1989; Mitrofanov 1999).

Bag boom towing is used on short distances on slow-flowing parts of rivers, lakes, and seas. Booms, in most cases, are made of logs (sometimes of metal pontoons), and they are connected by ropes, chains, or other means. This type of rafting is the least common (Ecological encyclopaedia 1999).

Losses are *unavoidable* during all kinds of timber rafting and can be divided into three *types*: (1) losses due to drowning (timber, being porous, absorbs water, which increases its density; sinking logs account for 57% of all losses); (2) process losses (logs ducking under booms, raft crashes, logs sticking on flood plains; these incidents account for 32% of all losses); and (3) other losses (logs breaking when they are dumped into water or piled up; some logs are left in storage yards; extra logs are used during indirect works; these losses account for 11% of all losses) (Manukovsky and Patyakin 2004).

Thus, most *losses* are connected with sinking due to density increases. In addition, product sometimes does

Photo 11.19 Impacts of timber rafting on surface waters can be characterized by the following factors: (1) increases in solid discharge; (2) pollution with matter emitted by timber; and (3) pollution with waste, branches, and sunken logs. The photo shows timber being floated to Vancouver, British Columbia, Canada (Photo credit: Tony Hisgett, 2 August 2006)

not reach the consumer due to deviations from a transportation route. In 1978, in the former USSR, those losses comprised 0.85% of all rafted timber (Gorshkov 1982). In the Mari El republic of Russia (area is 23,200 km^2), more than 1,100 m^3 of timber is lost every year during rafting, 5% of which is so-called fumed oak (Rozhentsov 2003).

Timber rafting impacts the following natural *components*: (1) surface waters; (2) ichthyofauna; and (3) soils. Impacts on surface waters can be characterized by the following *factors*: (1) increases in solid discharge; (2) pollution with matter emitted by timber; and (3) pollution with waste, branches, and sunken logs.

Solid discharges into water are connected with logs being rolled down from slopes and silt sticking to the logs. During transportation by water, silt is washed off and carried as a suspended or dragged drift (Gorshkov 1982).

Pollution with matter emitted by timber is the most serious problem. The amount of soluble matter in timber depends on species, age, place of growth, time of logging, length of storage period after logging, and other factors. It also changes considerably in different parts of the trunk. For example, there is 6.8–14.5% soluble matter in the bark of pine, fir, and aspen; in sapwood of the same species, this amount is just 0.72–1.75% (Fomintsev 1990). The amount is the smallest in the heartwood.

The main *types of matter* extracted by water include the following: (1) tannins (so-called 'hardening agents', which are phenolic compounds); (2) some polysaccharides (so-called 'gums' [pectins, starch] or carbohydrates of high molecular weight); (3) some carbohydrates of low molecular weight; and (4) inorganic salts (Fomintsev 1990; Manukovsky and Patyakin 2004).

Washout of water-soluble matter decreases exponentially. The first half is washed out in the first 2–7 days; then, the speed of washout drops rapidly. For instance, a drowned pine will contain only 36% of soluble matter in 5 years, and only 18% will be present in 18 years (Manukovsky and Patyakin 2004).

Pollution with waste, branches, and sunken logs (excluding emitted matter) is physical pollution. Its importance is not high.

The impacts on the *ichthyofauna* include (1) impacts on spawning grounds; (2) impacts of extracted matter; (3) timber waste sedimentation on the bottom; and (4) increases in the area of distribution of some animals.

Mechanical damage to *spawning grounds* by drifting logs and branches takes place. This damage has unfavourable effects on the spawning of many fish, decreasing their numbers. To protect spawning grounds, booms consisting of logs or metal pontoons are installed (Novikov 1999).

The impacts of *extracted matter* are controversial: They can be both positive and negative. Increases in the nutritive base for the fish are a *positive* effect. Extracts promote phytoplankton growth, providing food for the fish. Nevertheless, those organisms consume oxygen dissolved in water for respiration. After a certain threshold, phytoplankton starts to affect fish adversely.

Negative impacts on hydrobionts are connected with increases in acidity. Many types of extracted matter are toxic for hydrobionts. Plankton is the most vulnerable; benthos is the next to be affected.

Photo 11.20 During floating, many logs become waterlogged and sink to the bottom of the bodies of water. After many years of log drives, large quantities of wood have accumulated in certain areas. Because of the reduced oxygen and light levels, decomposition is greatly reduced and sunken logs, which may have sunk hundreds of years ago, have been preserved to this day. The photo shows the retrieval of logs in British Columbia, Canada (Photo credit: Underwater Logging Ltd., Canada)

Different species and their spawn have different sensitivities to the extracts. Poisoning of fish takes place if the total concentration of emitted matter remains at a level of 9 g/l for 24 h (Alekseenko 2005). The most dangerous are resinous substances and hardening agents. Salmon is the most sensitive to extracted matter (Fomintsev et al.1990).

Sedimentation of timber waste on the bottom of water bodies is also useful to a certain extent. It increases the biomass of bottom grounds with low productivity because colonies of caddis worms, ephemerans, and chironomids form on the timber substrate.

The boundary between *positive* and *negative* impacts lies in the *proportion* of timber rafting volumes and the water content of rivers. For example, a solution with the proportion of water and timber of 1:140–150 (2–3 mg extracted matter per litre) is toxic for planktonic organisms. Benthos is less sensitive: Proportions of 1:64 (fir matter) and 1:16 (pine extracts) – equal to concentrations of 5–26 mg/l – are harmless for it. For fish, toxicity develops at proportions between 1:128 and 1:150 (Manukovsky and Patyakin 2004).

Increases in the territories of some animals are due to the fact that insects, snails, lizards, and other organisms can be found on the trunks of rafted trees It is believed that timber rafting contributed to the spread of geckos (lizards that lay eggs with a long development period in tree trunks) (Sedlag 1975).

Logs being dumped into water have an *impact on soils* through some increase in erosion and removal of soil that clings to the logs, but, on the whole, it is negligible.

The impacts of timber rafting on the environment are illustrated by the Photos 11.19–11.20.

11.2.2 Reforestation and Plantation Development

Reforestation is a process in which new forest is generated on sites where logging and fires have taken place; that is, where forests once were. *Plantation development* is cultivation of artificial forest, similar to agriculture. The mean rate of reforestation and plantation development is illustrated in Fig. 11.5.

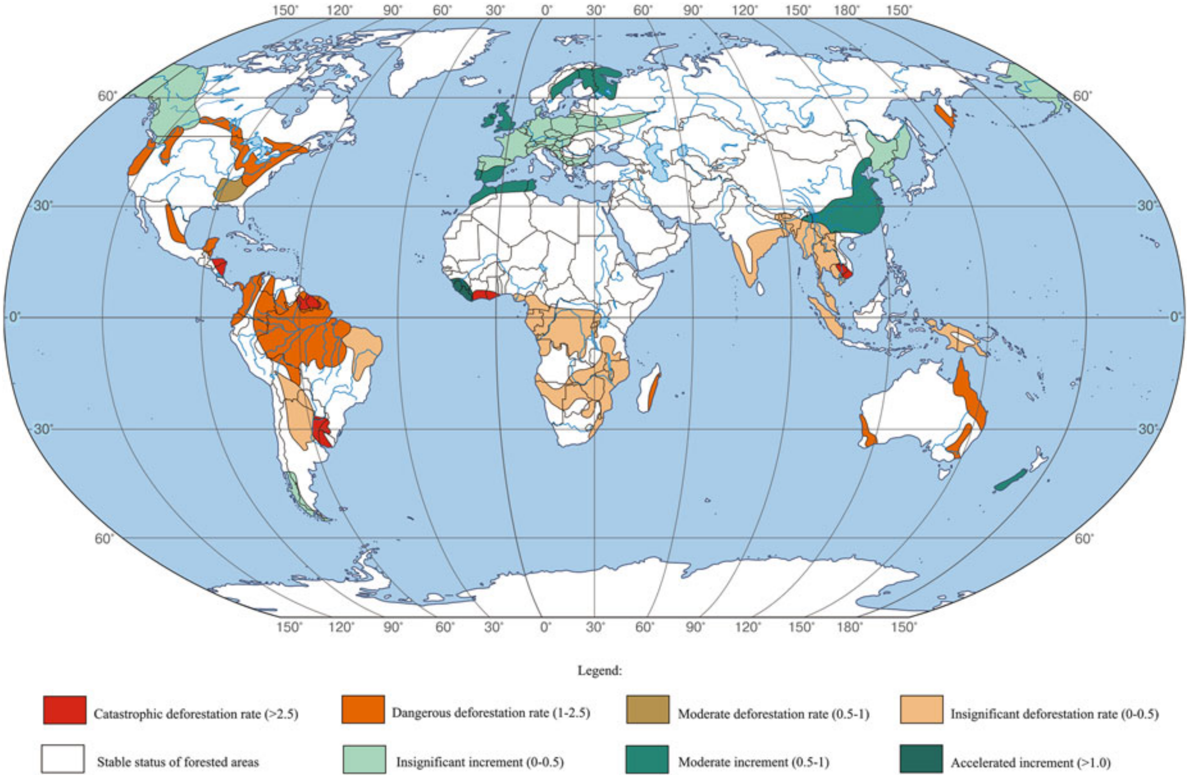

Fig. 11.5 Mean rate of deforestation or forested areas increment (percent per year) (Resources and environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of Sciences)

Photo 11.21 Plantation development is cultivation of artificial forest, similar to agriculture. It usually means the growing of monocultures. As a rule, plantation development leads to sharp decreases in biodiversity in comparison to less-disturbed forests that grow in similar conditions. The photo shows a pine (*Pinus taeda*) plantation in the United States. Plantations are usually easily distinguished from natural forests because the trees are planted in straight lines (Photo credit: U.S. Department of Agriculture Natural Resources Conservation Service, 21 May 2008)

Photo 11.22 Reforestation is a process in which new forest is generated on sites where logging and fires have taken place; that is, where forests once were. Among the countries with maximum scales of forest restoration works is China. By 2030, the government of the People's Republic of China plans to increase the forest coverage from today's 13.9–18% through forest replanting. The photo shows plantations of poplar (*Populus simonigra*) in north-west China designed for soil drift control (Photo credit: J.Y. Piel, Food and Agriculture Organization of the United Nations, image 17957, 1994)

Forest restoration can be conducted in two different *ways*: (1) *artificial* (i.e., creation of forest cultures; planting and sowing of trees) and (2) *facilitation of natural forest restoration* (i.e., creation of conditions that ensure fast repopulation by valuable tree species). This facilitation means leaving seed trees and small areas of forest unlogged (Doncheva and Pokrovsky 1999; Nikonov 2001).

Plantation development usually means the growing of *monocultures*. In 2000, the total area of forest plantations in the world was 187 million hectares. Approximately half of all planting is done on former forest areas, and another half is done on non-forest areas (Modern global changes 2006, vol 2). Between 1990 and 2000, the area of plantation forests increased by 3 million hectares a year (West 2006).

More than 60% of all forest plantations are located in Asia. For the countries with the *largest plantations*, the figures are the following (thousand hectares): China, 45,083; India, 32,578; Russia, 17,340; United States, 16,238; Japan, 10,682; Indonesia, 9,871; Brazil, 4,982; Thailand, 4,920; Ukraine, 4,425; Chile, 2,017; Great Britain, 1,928; Spain, 1,904; Vietnam, 1,711; South Africa, 1,554; New Zealand, 1,542; Austria, 1,043; Bulgaria, 969; France, 961; Argentina, 926; Venezuela, 863; Portugal, 834; Myanmar, 821; Philippines, 753; Algeria, 718; Nigeria, 693; Bangladesh, 625; Ireland, 590; Sweden, 569; Morocco, 534; and Cuba, 482 (Modern global changes 2006, vol 2)

Annual average *timber growth* on plantations, as a rule, is much *higher* than timber growth in conventional forests. For instance, average productivity of temperate forests in North America and Europe is 5 m^3/ha a year. On plantations, the annual timber growth in the United States is 15 m^3/ha a year, and on the North Island of New Zealand, it reaches 31–36 m^3 a year (Spurr and Barnes 1984). Thus, creation of ecosystems consisting of even-aged forest allows logging operations to obtain the maximal amount of wood per unit area within the minimal time.

Nevertheless, plantation development, as well as forest restoration, has a number of negative *environmental consequences*. These consequences are mainly connected with aerial chemical treatment and melioration.

The main *tasks* of aerial chemical treatment are (1) to increase soil fertility and (2) to regulate juvenile population composition. To accomplish the *first* task, mainly fertilizers are used. The use of fertilizers leads to increased timber growth, but it also results in considerable water pollution and has an impact on ichthyofauna (Munson et al. 1993).

To *regulate the natural juvenile population composition* formed on logging sites, other chemicals – *arboricides* – are used. Their impact on tree species has a selective character. For example, in young mixed pine-broadleaf forests, pine, which is the most valuable species, suffers from shading by small-leaved deciduous species (aspen, birch, willow, alder, and linden). Arboricides are disseminated in such forests, provoking the death of many of the deciduous trees, while coniferous trees receive much less damage.

Considerable research done on sites where arboricides have been used has shown that they have negative impacts on almost all *animal* species. These impacts include effects such as decreases in the *reproduction* intensity of many groups of animals, *reduction* of some animal population *numbers*, and provocation of *developmental defects* (Sokolov 2008). The impacts of *herbicides* are similar; besides, their use leads to drops in nitrogen and amounts of other nutrients in soils (Munson et al. 1993).

Forest melioration is applied widely in the taiga zone. In many cases, it is understood as forest draining. Melioration leads to productivity growth in dried forests, due to increases in root layer thickness, accelerated mineralization of organic matter, and improvement of tree root aeration (Handbook of forester 1980).

The *negative impacts* of forest draining are much more diverse: (1) the importance of drained forest ecosystems in sustaining oxygen and carbon balance in the atmosphere drops radically; (2) waters where drainage waters are dumped are polluted by turf bits and soluble decay products of accumulated organic matter, which results in drops in the oxygen content in water and leads to fish suffocation during winter (see Sect. 6.3); (3) rapid changes in the conditions in marsh ecosystems cause death of many plant and animal populations; and (4) there is also a catastrophic growth of fire hazard in the drained territories.

Apart from all that, plantation development often leads to *soil degradation*. For instance, in cultures of different species of larch in northern China, soil degradation is connected with changes in the nutrient cycle. Larch needles decay for a very long time, and it takes 4.4 years to mineralize forest litter. This process takes 0.9–2.4 years for birch and poplar.

At larch plantations, litter accumulation leads to thermal insulation of soil, decreasing its temperatures and limiting microbial activity. Declines in *fertility* are observed in the first generation and worsen after two rotations. In mixed cultures (with a share of deciduous trees and shrubs), recirculation of nutrients and sustainable soil fertility are more effective (Liu et al. 1998).

Impacts on soils also take place during *timber processing*. Moving equipment causes soil to become denser, which in turn decreases a soil's biological *productivity*. The growth of some cultures in itself can have negative impacts on soils. For instance, *soil erosion* on eucalyptus plantations is very intense (Modern global changes 2006, vol 2).

As a rule, plantation development leads to sharp decreases in *biodiversity* in comparison to less-disturbed forests that grow in similar conditions, but appeared naturally, or even those secondary forests that grew without human interference.

The impacts of plantation development and reforestation on the environment are illustrated by the Photos 11.21 and 11.22.

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Internet Resources

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12 Transport

Abstract
The term *transport* has different meanings. In the narrow sense, it is an aggregate of facilities that are meant for the relocation of people and cargo. In the wider sense, it is the whole aggregate of infrastructure, management, transport facilities, and transporting enterprises. To get a driving force, all kinds of transport use mechanical devices to transform various sorts of energy into mechanical energy. When cartage is used, the muscular power of animals is employed, which is based on the transformation of chemical energy. Transport can be categorized by the type of conveyance (cargo or passengers) and by the 'age' (the most ancient ones are water transport and cartage, followed by railway, motor, pipeline, and air transport). The importance of different kinds of transport changes with the course of time. For instance, the significance of cartage has been declining steadily, and at present, its importance is extremely low. For a very long time (at least until intercontinental railroads appeared in the second half of the nineteenth century), water transport was the most significant. As for now, identification of the most important kind of transport is not very relevant, as each of them has its own 'niche' with regard to the nature of a cargo, the terms of delivery, and so on.

Keywords
Environmental impact • Natural components • Transport • Mortality • Pollution • Transportation • Cargo • Cargo handling • Transport infrastructure

12.1 Automobile Transport

In the *wide* sense, a *motor vehicle's* impact on the environment happens during its manufacture, usage, service, and repair; the production of fuels and lubricants; building and operation of roads; the development of a service network; and the disposal of used vehicles, tyre casings, and other technological fluids.

During its life cycle, every car produces a large amount of reusable resources (e.g., used engine oil) and waste products, which is 10 times more than the weight of the car (Hotuntsev 2002). For instance, the utilization of used *car tyres* is a serious problem. Annually, 280 million tyres are accumulated in the United States; 35 million, in Great Britain; and ten million, in Australia. At the present time, only 20% of the car tyres are utilized or burnt; the remaining 80% are taken to dumps or placed in landfills (Rudzinski et al. 2001).

This section considers mainly the impacts that are caused by the *usage* of vehicles and also by the building and operation of motor *roads*.

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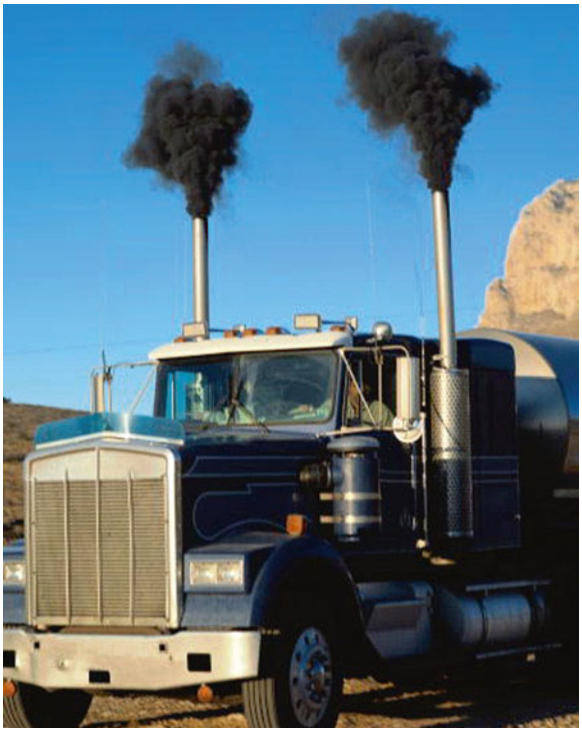

Photo 12.1 The most significant impact of automobile transport is air pollution. The main pollutant is burnt gases from engines. The main emissions component is carbon dioxide; in consideration of toxicity, however, the most important pollutants are carbon monoxide, and lead in gasoline and sulphur dioxide in diesel engines. The photo shows diesel smoke from a big truck (Photo credit: U.S. Environmental Protection Agency)

Automobile transport contributes considerably to human *mortality*. The *first case* of a human death caused by a traffic accident happened in London in 1896. Now, 1.2 million people lose their lives and millions are injured annually (Black 2005).

The *impacts* of automobile transport on the environment can be divided as follows: (1) air pollution; (2) pollution and breaking of surface and subsurface drainage; (3) soil pollution; (4) loss of lands; (5) fauna impacts; (6) flora impacts; (7) transformation of relief and the geological environment; and (8) noise impacts and vibration.

Air pollution is the most significant impact of automobile transport. Its main *components* are (1) burnt engine gases; (2) crankcase fumes; (3) fuel evaporation from tanks, carburettors, or hoses; (4) products of abrasion of tyres, brakes, and other parts of a vehicle, and (5) products of a roadbed's wear.

The main pollutant is *burnt gases* from engines. The *main emissions component* is carbon dioxide; in consideration of toxicity, however, the *most important pollutants* are carbon monoxide and lead for gasoline engines, and sulphur dioxide for diesel engines. This pollution is conditional on some important factors, including the design characteristics of the engine and the fuel being used; other important factors include the conditions of operation, the development of networks of service stations for diagnosing engine performance and toxicity and for tuning engines, the state of roads, and the level of traffic management.

In many countries, automobile transport makes the *main contribution* to air pollution. In Germany, for instance, automobile transport accounts for the following percentages of major pollutants: carbon monoxide, 60%; nitric oxides, 54%; hydrocarbons, 37%; sulphur dioxide, 2%; and dust, 4%. Annual *tyre abrasion* in this country is estimated at 120,000 ton (Environment 1999, vol 1).

Construction of roads often causes changes in *surface flow* and *groundwater conditions* as consequences of the creation of new geomorphologic forms during the construction of a roadbed. In cases when a road embankment interrupts the natural run-off, *upstream* over-wetting, rises in the levels of subsoil water, gradual swamping, and the transformation of flora and fauna occur. The *downstream areas* are drained of water and, consequently, biogeocenosis is transformed. The changes in run-off are especially intensive when roads are constructed in marshlands.

The pollution of *surface waters* happens in *two ways* (Govorushko 2003). *The first one* includes transfer into water bodies of mechanical (sediments, suspensions, and emulsions) and chemical (dissolved substances in the ionic and molecular forms) pollutants, which are generated during construction and use of the roads. The content of pollution in a flow depends on the area, intensity of traffic, and other factors. In many areas, the main pollutants are chemical substances that are used to counteract ground surface icing (chlorides; nitrates; phosphates and sulphates of sodium, calcium, and magnesium; spirits; and glycols). The *most widely used substances* are chloride compounds, particularly sodium chloride and calcium chloride.

The second way includes sewage disposal by auto transport enterprises. The *main pollutants* are oil products, alkalis, lubricoolants, and others that are generated during car washing, servicing of accumulators,

Photo 12.2 Traffic jams increase air pollution many times. The photo shows a transport collapse in Moscow (Russia), on 30 October 2006. In many cases, 8–10 h were required to drive a distance of 10 km (Photo credit: I.S. Seleznev)

Photo 12.3 The numbers of deaths of animals on roads are extremely high. For example, in the United States, one million vertebrate animals die on roads every day. Ungulates, as animals having a large home range, often are involved in collisions with cars. The photo shows a dead Siberian stag after a collision with a motor vehicle in Primorsky Krai, Russia (Photo credit: A.M. Panichev, Pacific Geographical Institute, Vladivostok, Russia, 1999)

repair of coolant systems, and other maintenance and repair activities.

Soil pollution takes place in a relatively narrow wayside (100–150 m, up to 300 m). It is caused by the settling of *lead compounds* and other metals (copper, zinc, nickel, vanadium, cobalt, and molybdenum) from the atmosphere due to an engine's burnt gas emissions and metal parts wear. A large contribution to soil pollution is made by *de-icing salts*. Chlorides penetrate into the soil the deepest, reaching groundwater.

Photo 12.4 Automobile transport contributes to bioinvasions of plants and animals. For example, the Asian tiger mosquito, *Aedes albopictus*, was spread via the international tyre trade (due to the rainwater retained in the tyres when they were stored outside). It was accidentally brought from Japan to the western hemisphere in the mid-1980s with used tyres. Since then, this species has rooted itself in the United States, Argentina, Brazil, Guatemala, the Dominican Republic, Cuba, and Mexico. The tiger mosquito is associated with the transmission of many human diseases, including the following: Dengue fever, West Nile fever, and Japanese encephalitis. The photo shows used tyres in the United States (Photo credit: Delaware Department of Natural Resources and Environmental Control)

Photo 12.5 One of the ways surface waters are polluted is sewage disposal by auto transport enterprises. The main pollutants are oil products, alkalis, lubricoolants, and others that are generated during car washing, repair of coolant systems, and other maintenance and repair activities. The photo shows cars being washed in India (Photo credit: S. Avvannavar)

Regarding the size of *condemnation of land,* automobile roads and other components of the infrastructure occupy a high place among the branches of industry. For instance, in the United States, roads and waysides occupy about 1% of the territory of the country, which is approximately equal to the area of Austria (Elaine 2003); in the Federal Republic of Germany, it is 4.3% (Environment 1999, vol 1). The area under direct ecological influence is much larger. So, in the United States, 19% of the territory is affected (Forman 2000).

The influences on *fauna* can be both *positive* (the waysides act as ecological niches for synanthropic and semi-synanthropic species of birds and mammals; the roads are migration passages) and *negative* (creation of ecological obstacles, deaths of animals in collisions with cars, the destruction of the animals' habitat, etc.).

Roads are often *barriers* to the migration of animals. For them, the ability to overcome a road depends basically on its width and the heaviness of traffic. Observations of wild roe in Switzerland showed that with a traffic intensity of 2,000 automobiles per a day, only 20% of the animals would cross a road. With an intensity of 6,000 automobiles per a day, a road becomes an insurmountable obstacle (Govorushko 2009).

The most '*bloody periods*' are spring and autumn, twilight and dawn. The following are *reasons* why animals may attempt to cross a road: (1) the presence of food on it or nearby (the dead animals themselves become a source of food for birds; food waste is thrown out of cars); (2) heated asphalt and road lighting attract reptiles and night insects; and (3) migration.

Animal *deaths* caused by collisions with motor vehicles occur, *first of all*, with animals having high mobility (birds), with animals having definite peculiarities (slow movement, sluggishness, and weakness of hearing or sight), with those showing vulnerable behaviours (stop when being lit by headlights, assume protective poses in case of danger, night activity), and also those having a larger home range (amphibians and hoofed mammals).

The numbers of *deaths* of animals on roads are extremely high. For example, in the Netherlands, 159,000 mammals and 653,000 birds die annually; in Bulgaria, seven million birds; and in Australia, five million frogs and reptiles. In the United States, one million vertebrate animals die on roads every day (Forman and Alexander 1998).

Automobile transport contributes to *bioinvasions* of *plants* and *animals*. For example, the *Asian tiger mosquito*, *Aedes albopictus*, was accidentally brought from Japan to the western hemisphere in the mid-1980s with used tyres. Since then, this species has rooted itself in the United States, Argentina, Brazil, Guatemala, the Dominican Republic, Cuba, and Mexico.

The influences on the *geomorphologic* and *geological* environment are caused by the removal of considerable amounts of ground, which leads to transformation of relief (excavation and embankments). The creation and use of roads often intensify geomorphologic processes.

The *noises* of road traffic are caused by working engines, wheels, beeps, and so on. Levels depend on the structure of traffic (the proportion of trucks), the nature of the roadbed, traffic intensity, drivers' behaviours, and other factors. Slowly moving cars have prevailing noise of engines, and at speeds faster than 50 km/h , the noises of the tyres dominate; trucks always have loud engine noise (Heinrich and Hergt 2003).

The *range* of noise propagation depends on the peculiarities of an area, the presence of vegetation, and the level of development. In advanced countries, much of the population is exposed to noise. In the Federal Republic of Germany, for instance, 40% of the population suffer from noise (Environment 1999, vol 1).

The impacts of automobile transport on the environment are illustrated by Photos 12.1–12.5.

12.2 Railway Transport

Railway transport is a kind of transport that conveys cargo and passengers on railroads. The *total length* of railroads over the whole world in 2006 was 1.37 million kilometres. A total of 148 countries have railroads. The *leaders* are (thousands of kilometres) (1) the United States, 226; (2) Russia, 128; and (3) China, 86 (http://en.wikipedia.org/wiki/List_of_countries_by_rail_transport_network_size). The *volumes* of freight traffic are high mostly in Russia, the United States, Ukraine, Poland, France, Romania, and the Federal Republic of Germany. Main railways of the world are illustrated in Fig. 12.1.

Railway transport systems consist of large numbers of *enterprises*: locomotive and wagon depots, factories (sleeper impregnation, rubble, rolling stock, track machine repairing, etc.), flashing and steaming stations, disinfection and washing stations, railroad stations, and other facilities.

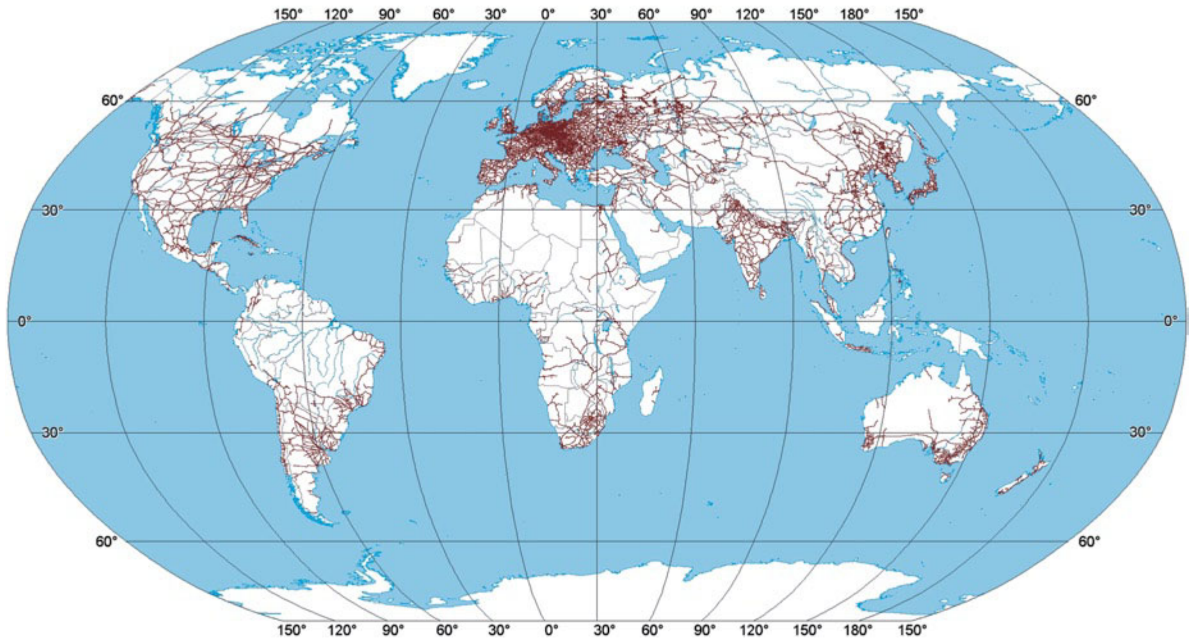

Fig. 12.1 Main railways of the world (Source: Joint Research Centre Institute for Environment and Sustainability ©European Communities 2009. Reproduced with permission of Publications Office of the European Union)

Virtually all *components* of the natural environment are exposed to the impacts of railway transport, such as the *following* (Carpenter 1994): (1) air; (2) surface and ground water; (3) soils; (4) geological and geomorphologic environments; (5) fauna; (6) flora; (7) noise impacts; and (8) land withdrawal.

The main pollutant of the *atmosphere* at the stage of railroad *construction* is the non-organic *dust* of the sand and crushed stone that is created during mining, conveyance, and laying of ballast. The share of *gaseous* pollutants (carbon monoxide, nitrogen oxides, sulphurous anhydride, and soot) generated in the burning of fuels and blasting is relatively small.

During the *operation* of railroads, the ratios of volumes of pollutants change. The main factors polluting the atmosphere in railway transport are *burnt gases* from diesel locomotives, which contain benzol, lead, soot, formaldehyde, toluol, and xylol (Bulayev 2006).

The *stove heating* of the carriages also has some impact. The main pollutants emitted by *rolling stock* are carbon monoxide, nitrogen oxides, sulphur dioxide, hydrocarbons, and soot.

The *goods* being transported themselves are sources of considerable pollution, which is caused by the *leakage* of those goods because of looseness; intensive emissions during loading, unloading, and transportation; and also by blowing-off of dust-like fractions with the wind while a train is moving.

Some of the railway *enterprises* causing air pollution are sleeper impregnation, rubble, repair factories, disinfection and washing stations, and boiler houses, which emit substances such as particulate matter (dust and soot), carbon monoxide, nitrogen and sulphur oxides, and various varnish and paint substances (Tskhovrebov 1996).

In particular, dust emissions from railway repair enterprises (basically metal oxides) over the territory of the former Soviet Union are 380,000 ton per year (Muravyev et al. 2000).

The impacts on *surface waters* consist of their withdrawal and pollution. The *leakage of oil products* is a main source of pollution in the use of rolling stock. It also occurs when washing a train and changing coolant liquid in diesel locomotives; the *main pollutants* are synthetic surfactants (SS), oil products, phenol, hexavalent chromium, acids, alkalis, and organic and non-organic suspended substances.

Certain problems are raised by *oil* oozing from leaks in various locomotive devices and parts of carriages. *Faecal drains* and *waste* disposal from passenger cars also have some significance. Stationary

Photo 12.6 Not infrequently, railroad transport modifies the geologic environment. Underground railway systems are of primary importance. The first metro system, the London Underground, was opened in 1863. As of 2010, there are approximately 140 metro systems in the world. The photo shows the Pyongyang Metro (North Korea). It has operated since 1973 and is the deepest metro in the world, at some 110 m underground (Photo credit: http://en.wikipedia.org/wiki/North_Korea)

Photo 12.7 The goods being transported themselves are sources of considerable pollution, which is caused by the leakage of those goods because of looseness; intensive emissions during loading, unloading, and transportation; and also by blowing-off of dust-like fractions with the wind while a train is moving. The photo shows coal cars in Ashtabula, Ohio (United States) (Photo credit: http://en.wikipedia.org/wiki/Coal, 26 September 2004)

Photo 12.8 The scales of contamination in rail transport increase many times in case of emergency. As a result of a derailment of a freight train on 15 June 2005, near Rzev (Tver oblast, Russia), 21 tanks with fuel oil overturned. Altogether, about 300 ton of oil products were released. Removing the contaminated surface layer of soil and processing the roadside with fire foam in order to prevent inflammation of oil products in the course of repair and renewal operations are shown (Photo credit: V. Pavlov, Greenpeace Russia, 21 June 2005)

sources of waste include considerable volumes of sewage, containing mineral, suspended, and organic substances; phenols; oil products; synthetic surfactants; different metals; and other materials.

Soil impacts basically occur in relatively narrow strips along railways and near enterprises. The *main pollutants* near tracks are coal and ore dust, oil products, and salt. Pollution consisting of metal dust generated as a result of intensive abrasion of cast iron brake pads is also of some significance (Tskhovrebov 1996).

The impacts on the *geological* and *geomorphologic* environments consist of factors such as withdrawal and movement of geological materials, and intensification of geomorphologic processes. The impacts on *fauna* consist of blocking by railways of animal migration routes and creation of problems for selected species (Rudsky and Sturman 2006).

Railways are distribution channels of invasive *plant* species. The stripes alongside railways serve as places for naturalization and dissemination (Filippova and Perevoznikova 2006). For instance, about 70 species of plants were brought to the territory around Moscow (Russia) in the second half of the nineteenth century along railways. Approximately 50 of them were disseminated widely (Geoecological principles of designing of natural-engineering geosystems 1987).

The main source of *noise* is rolling stock. The noise of *locomotives* is caused by motor ventilators, compressors, generators, traction engines, and so on; for motor carriages of electric trains, they are motor compressors and traction engines. Noise is also generated by *wheel strokes* over railing junctions, knocks of *automatic couplers*, rattling and knocks of *brake rods* and pads, *braking*, and other factors.

The noise from railway transport *enterprises* is generated during activities such as the operation of different machinery and equipment and ventilation. Some sources of intensive noise at stations are shunting operations, compressors, blow-off of railway points, speakerphones, conveyors, and cranes.

Land withdrawal related to railway transport is not large. For instance, a four-lane highway requires 5.6 ha of land per kilometre, but four railways occupy 2.5 ha/km, and the number of passengers being transported by automobiles is 13 times less (Wrong side of the tracks? 1991).

The impacts of railway transport on the environment are illustrated by Photos 12.6–12.8.

Photo 12.9 In the process of building a pipeline over land, the following primary stages of work are performed: (1) geological engineering survey and (2) route clearing. A cleared area can be an insurmountable obstacle for movement of animals. Falling on the steep slopes results in intensification of erosion processes. The photo shows the cut-through for laying of an oil pipeline on Sakhalin Island (Russia) (Photo credit: V. Kantor, Greenpeace Russia, 27 June 2005)

12.3 Pipeline Transport

The transportation of *oil* and *gas,* and also the products of processing (e.g., ammonia and ethylene), with pipelines is widespread. More than 70% of extracted oil is transported with pipelines (both by land and by sea) (Stesin 2000). Their *total length* is more than 400,000 km. The *largest* ones are the Druzhba oil pipeline, laid from western Siberia to Europe, with a length of 5,500 km, and also Canadian oil pipelines from Redwater to Port Credit (4,800 km) and from Edmonton to Montreal (3,200 km) (Rodionova and Bunakova 1999).

Pipelines are also used for transporting *materials* such as ground mineral carbon, ores and ore materials, limestone, phosphate, powder-like plastics, and construction materials. Besides the pipelines themselves, the *infrastructure* also consists of head and intermediate pump stations, receiving and distribution stations, control stations, approach roads, and so on.

In the process of *building a pipeline* over land, the following *stages* of work are performed (Environmental assessment 1992): (1) geological engineering survey; (2) route clearing; (3) making ditches; (4) laying the pipes along the route of the pipeline; (5) pipe bending; (6) welding; (7) wrapping the pipes with polymeric bands; (8) applying an insulating coating; (9) installing cathodic corrosion protection systems; (10) laying the pipes into ditches; and (11) ditch backfilling.

In the process of building pipelines in the open *sea,* they are placed on the bottom fixed with anchorages (concrete slabs, blocks, etc.). If a pipeline must be laid deeper, ditches are made with underwater digging machines. To lay the pipes, *pipe-lay ships* are used. Artificial filling of underwater ditches is rarely done, as ditches usually are filled as a result of natural processes (e.g., roughness and currents).

On the whole, the influence of building works when *constructing* pipelines does not differ in essence from influences when constructing other industrial projects. The exception is *underwater* laying, which damages water ecosystems considerably. Such cases occur often, as besides building pipelines on the sea bottom, laying numerous underwater crossings through rivers is often required.

Rapid growth of concentrations of suspended soil particles occurs in river sections several kilometres long during the digging of *channel ditches*. This material changes the conditions in the habitats of fish, plankton, and benthos. Feeding water and spawning spots get

Photo 12.10 The next stages in building a pipeline over land are: (3) making ditches; (4) laying the pipes along the route of the pipeline; (5) pipe bending; (6) welding; (7) wrapping the pipes with polymeric bands; (8) applying an insulating coating; (9) installing cathodic corrosion protection systems; (10) laying the pipes into ditches; and (11) ditch backfilling. The photo shows the laying of the Sakhalin Island-Khabarovsk-Vladivostok gas pipeline in southern Primorsky Krai (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 25 September 2010)

dirty or are completely destroyed. Wintering pits are often filled during underwater soil storage. Fish are struck with hydrodynamic shock waves during *blasting*. The radius of the affected areas (with dead or injured fish) reaches several tens, sometimes hundreds of metres. During *ditch backfilling* from floating vehicles, the secondary pollution of water bodies occurs (Telegin et al. 1988).

While a pipeline is being used, the *main sources* of impacts are (1) the pipelines themselves; (2) the products being transported; and (3) the heat of substances being transported.

Basically, the impacts of the pipelines *themselves* involve land withdrawal and obstruction of *migration* routes of a number of animals. For example, in 1969 the spring migration of Taimyr reindeer from winter pastures in the Yenisei River valley was interrupted by the Messoyakha–Norilsk gas pipeline (Russia). The animals were moving along it, searching for ravines or parts of the pipeline covered with ice, where they got over it. The reindeer chose a new path to bypass the pipeline in autumn of 1969 and spring of 1970 (Bazmat et al. 2002).

Additional *slope loading* near pipelines can provoke *landslides*. In the area of *permafrost* soil, pipelines contribute to *swamping* (due to creation of obstacles to surface flow and additional dumping because of snow accumulation) and activation of *erosion processes* (due to destruction of vegetation cover and instability of filled soils).

The most intense *source* of impacts to the environment is *transported products*. During normal pipeline transport, pollution of the atmosphere occurs (emission of oil in reservoirs, loading and unloading operations at transfer stations, gas leakages, etc.).

For example, as a result of *gas leakage* from a linear pipeline portion with a length of 1,100 km in northwestern Siberia, more than 100,000 ton of hydrocarbons are emitted to the atmosphere annually. Compressor plants emit 30,700 ton of various pollutants, including hydrocarbons, 58%; nitrogen oxides, 25.7%; and carbon monoxide, 15.6% (Geoecology of the North 1992).

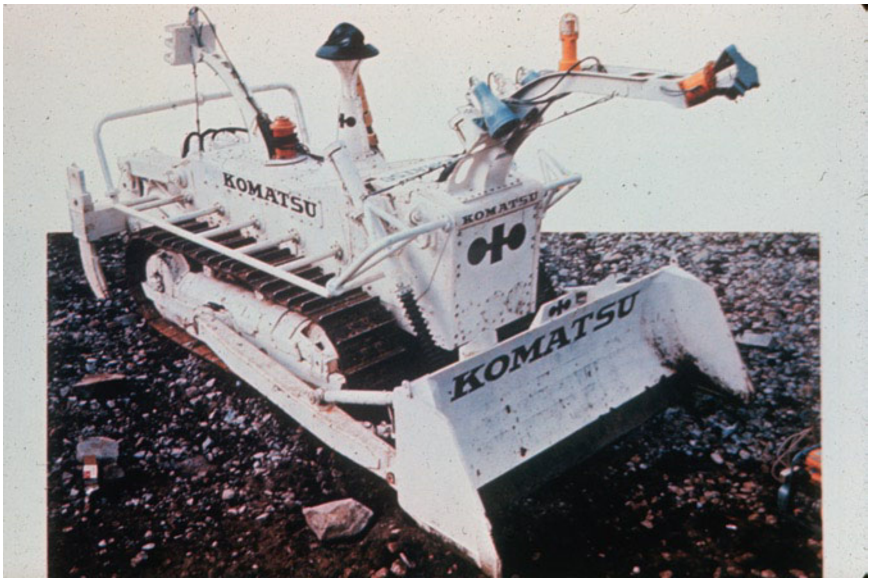

Photo 12.11 In the process of building pipelines in the open sea, they are placed on the bottom fixed with anchorages (concrete slabs, blocks, etc.). If a pipeline must be laid deeper, ditches are made with underwater digging machines. The photo shows an underwater bulldozer (Photo credit: National Oceanic and Atmospheric Administration)

Photo 12.12 The most intense source of impacts of pipelines to the environment is transported products. During normal pipeline transport, pollution of the atmosphere occurs (emission of oil in reservoirs, loading and unloading operations at transfer stations, gas leakages, etc.). Spatial scales and intensities of impacts increase markedly in case of an incident. An oil leak after an accident on a pipeline near Nizhnevartovsk (West Siberia, Russia) is shown here (Photo credit: M. Lodewijkx, Greenpeace International, August 1999)

Spatial scales and intensities of impacts increase markedly in case of an incident. Emergency oil leakages from *underwater pipelines* are the *most dangerous*. The reasons for leakages can be damage due to natural processes (scouring by ice *jams*, *hummocks*, and *icebergs*; impacts by *submarine landslides*; etc.), wear, and personnel not adhering to operating instructions (Khaustov and Redina 2006).

In Russia, about seven million tons of oil is *spilt out* at underwater river crossings and near shorelines. In 1988 alone as a result of an oil pipeline breach in the Samotlor field, 110,000 ton of oil flowed out into the lake of the same name (http://neftegaz.ru/library/?wr=8&wrpar=100&wrid=1372). *Accidents* are known to have occurred in the North Sea (where 4,800 km of pipelines are used), on the shelf of Saudi Arabia, in the United States, and in other areas (Patin 1997).

In case of accidental spills on land, *two aspects* of impacts upon *plants* can be identified (Korobov 2004): (1) malfunction of physiological processes due to covering of the surfaces of the trunks and leaves; and (2) plant intoxication with toxic components of oil. In most cases, vegetation perishes and its regeneration starts after 2–3 years. General oppression, necrosis, and tumours are typical in the surviving specimens (Dorozhukova and Yanin 2002).

Heat impacts of oil transported in pipelines are especially significant in areas of *permafrost*. These impacts include changes in the thermal and humidity conditions of the soils, and the appearance of *thermokarst* and *frost swelling*.

The impacts of pipelines on the environment are illustrated by Photos 12.9–12.12.

12.4 Air Transport

At the beginning of 2003, the *world's aircraft fleet* included 17,770 passenger aircraft; 89,129 military aircraft; 26,500 civil helicopters; and 29,700 military helicopters (http://www.gama.aero/aboutGAMA/industryFacts.php). In addition, there were more than 200,000 private single-engine aircraft.

The impacts of air transport can be subdivided into the impacts of *aircraft* themselves and of *airlines*. The *operation* of aircraft and helicopters, first of all, has impacts on the atmosphere (e.g., pollution of air with burnt engine gases, and decreases in ozone concentrations in the lower stratosphere).

The *intensity of pollution* and the composition of the burnt gases are different at the *different stages* of aircraft engine operation. During *idle running* (parking), *taxiing*, and *approach landing*, the quantity of carbon monoxide in burnt gases increases, but the quantity of nitric oxide decreases. During flight, emissions of carbon monoxide decrease, but emissions of nitric oxides increase.

The *greatest pollution* (emission of soot) occurs during take-off and climb (Vladimirov and Aleksashina 1988). The take-off of one big aircraft produces the same amount of pollution as 8,000 cars do; at the same time, as much oxygen is consumed as 50,000 ha of forest produce in 1 day (Rudsky and Sturman 2006).

Soil and *surface waters* are polluted by excess fuel that aircraft have to discharge in case of emergency to decrease the touchdown weight. The amount of fuel discharged varies from 1,000–2,000 to 50,000 l. *Mainly*, the fuel is dispersed in the atmosphere. The share of non-evaporating fuel reaching the ground surface in the form of drops depends on the temperature of the air and the height of the discharge. It amounts to up to *several percent* (Naumova 2004).

It also should be noted that *noise impacts* can affect large areas. For example, aircraft acoustic discomfort in the Moscow region affects 5% of the territory (Geoecological fundamentals of protection 1991). It is believed that about 2–3% of the population of Russia at the present time are exposed to aircraft noise that exceeds exposure standards.

Levels of aircraft noise *depend on* the direction of runways and flight routes, intensity of flights during the day, seasons, types of aircraft that are based at a given airport, and many other factors. The *levels of noise* in an area in case of an airport's 24-h intensive operation are 80 dB in the daytime and 78 dB at night; maximum levels vary from 92 to 108 dB (Govorushko 1999).

It is known that aircraft contribute to the spread of *alien species*, especially insects. Often air travel leads to the spread of *diseases*. For example, the transportation of the protozoan *Plasmodium falciparum* by aircraft caused repeated infective episodes of *malaria* near airports in Belgium, the Netherlands, Great Britain, France, Italy, Spain, and Switzerland (Lounibos 2002).

As for the environmental impacts of *airlines*, the *main sources* of environmental pollution are airports and the equipment that is based at them. Their share of consumed water and all kinds of fuel is more than 90%, and, therefore, they account for the greatest amounts of waste

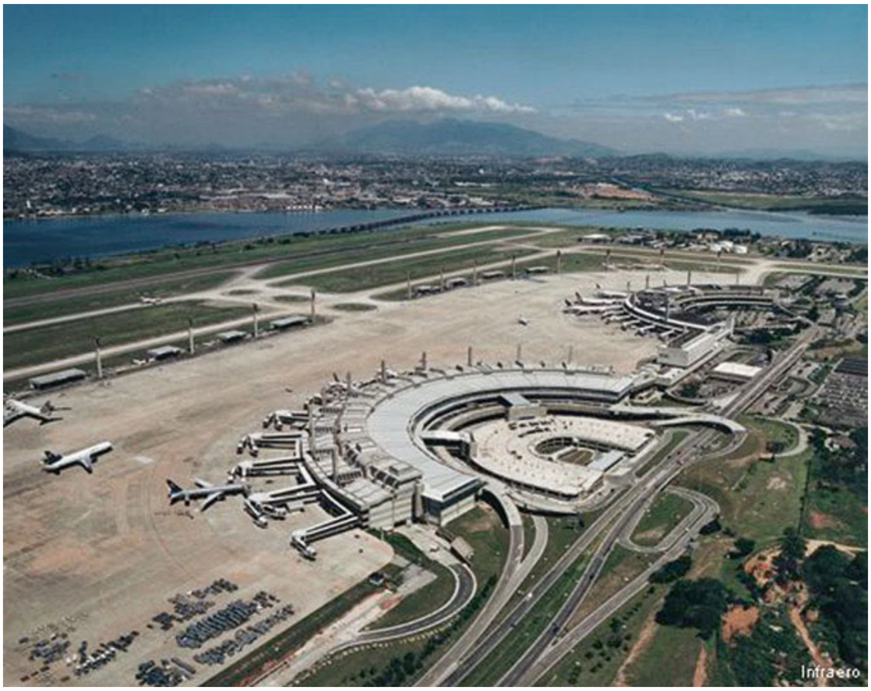

Photo 12.13 Large airports occupy vast territories. They include flight strips, bearing tracks, air terminal buildings, buildings and structures for aircraft maintenance, and other structures. The photo shows the Rio de Janeiro-Galeão International Airport (Photo credit: http://en.wikipedia.org/wiki/Airport, 8 April 2007)

products that pollute the environment. The *impacts of airlines* include, first of all, pollution of surface waters, noise, and electromagnetic impacts. Main air routes and the largest airports are shown in Fig. 12.2.

The pollution of *surface waters* comes from *three sources* (Govorushko 1999): (1) waste water (from buildings and aircraft service facilities basically); (2) sullage (from buildings and facilities for transportation services–air terminals, hotels, etc.); and (3) airline surface flow (from aircraft technical bases, areas for development works, aircraft washing and de-icing processes, apron and airport land side, etc.) that is formed due to melting snow and rainwater.

The *composition* of waste water is closely related to things such as the kinds of production, feedstock, and various extra products involved in processes, and also to the course of those processes, and the kind and performance characteristics of production equipment.

The *sewage* of airport production departments and other airline facilities *contains* benzol, acetone, oil products, acids, alkalis, dissolved metals, and other polluting substances, and also weed- and pest-killing chemicals used in agriculture. It is typical for the surface flows from airports to contain mineral suspensions, oil products, dissolved organic admixtures, and nitrogen-containing substances.

The *soil* around airports is polluted with heavy metal salts and organic compounds up to 2–2.5 km away. In autumn and winter, de-icing of aircraft and removal of snow and ice from the surfaces of airports are executed. Active *de-icing* preparations and reagents are used during those processes that contain urea, ammonia saltpetre, and synthetic surfactants, which also contaminate the soil.

The main *sources* of *noise* at airline facilities are aircraft and auxiliary power houses, starting units, special aerodrome service vehicles, and machining and technological facilities. The *levels* of jet aircraft noise at distances of 5–100 m are 120–140 dB.

The *sources* of *electromagnetic fields* are radio and radar equipment comprising air traffic, navigation, and landing management systems. Radio stations, Doppler radars, actual speed and drift angle measuring devices,

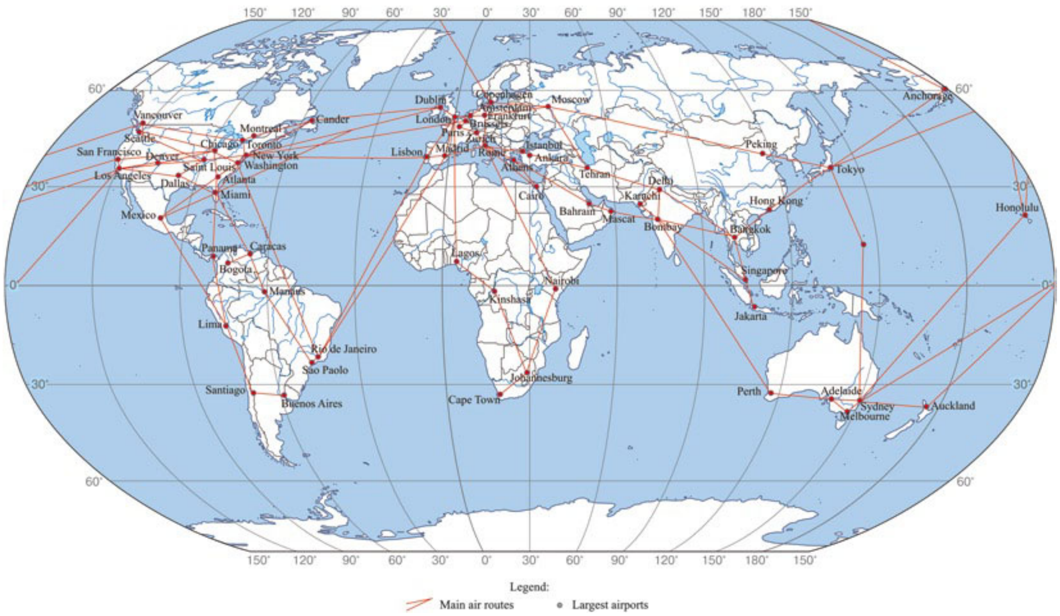

Fig. 12.2 Main air routes and largest airports (Resources and environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of Sciences)

Photo 12.14 The intensity of pollution and the composition of the burnt gases are different at the different stages of aircraft engine operation. During idle running (parking), taxiing, and approach landing, the quantity of carbon monoxide in burnt gases increases, but the quantity of nitric oxide decreases. During flight, emissions of carbon monoxide decrease, but emissions of nitric oxides increase. The greatest pollution (emission of soot) occurs during take-off and climb. The photo shows a plane taking off in Iceland (Photo credit: I. Kelman (http://www.ilankelman.org))

Photo 12.15 Air transport has various technogenic physical impacts. The sources of electromagnetic fields are radio and radar equipment comprising air traffic, navigation, and landing management systems. Radio stations, Doppler radars, actual speed and drift angle measuring devices, radio altimeters, radio beacons, and other equipment are included. The photo shows the radar stations of an aircraft navigation system in the Velikaya Kema settlement (Primorsky Krai, Russia) (Photo credit: A.M. Panichev, Pacific Geographical Institute, Vladivostok, Russia, 10 June 2005)

radio altimeters, radio beacons, and other equipment are included.

On the whole, the impacts of air transport on the environment are important enough. At present, it accounts for 3% of the world's man-made emissions of carbon dioxide (Lynes and Becken 2002), and it has certain *climatic* consequences (Asaturov 2005). *Aviation* accounts for about 3.5% of total anthropogenic pollution (Yanovsky et al. 2004).

The impacts of air transport on the environment are illustrated by Photos 12.13–12.15.

12.5 Water Transport

Water transport accounts for 60–67% of the world's freight turnover, according to various sources. *Fluid cargo* accounts for the greater portion of goods transported by water; the share of dry cargo is a bit smaller. Fluid cargo is represented mainly by oil and oil products. The transportation of *bulk cargo* (iron ore, grain, coal, phosphates, bauxites) comprises more than half of the traffic of *dry cargo*. Regions of most intensive navigation are shown in Fig. 12.3.

The impacts on the environment of water transport are associated with the following *factors*: (1) ships; (2) transported cargo; and (3) activities aimed at servicing water transport (channel dredging; building of ports, locks, and channels, etc.)

Water transport has negative impacts mainly on *surface waters*, and *aquatic flora and fauna* are affected. *Atmospheric air* is exposed to impacts to a lesser extent. The impacts on other components of the environment are local and are relatively minor.

During water transport activities, pollution occurs mainly as a result of the following *operations*: (1) dumping of ballast water; (2) dumping of bilge, sanitary, and waste waters, and garbage; (3) transportation

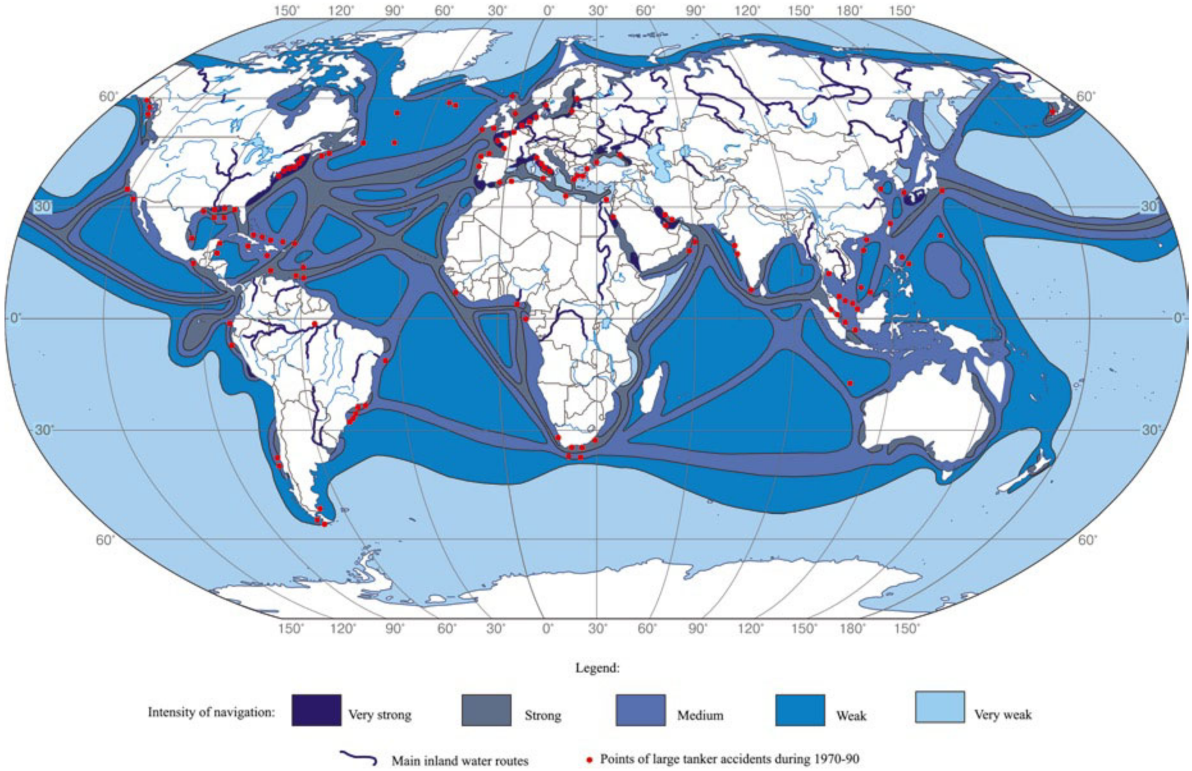

Fig. 12.3 Region of most intensive navigation (Resources and environment 1998; Maksakovsky 2006)

of freight and accidents; (4) transfer operations; and (5) running of ships' engines.

Oil transportation is the most dangerous regarding impacts on the environment. The dumping of tankers' ballast water is the most *powerful* source of impacts, providing more than 50% of oil pollution. Such a considerable contribution is explained by the fact that it is impossible to unload an oil tanker completely. Some of the oil remains on the walls and bottom of a cargo space.

The whole surface of the inside walls of the cargo space in a tanker of 100,000 ton displacement is about 80,000 square metres. About 0.4% of the transported volume–that is, 400 ton of oil–*remain* there after the oil is unloaded (Keselman and Glaz 1983). The draft of an empty tanker is small, and it loses its course-keeping qualities. To avoid this problem, *ballast* (sea-water) *is pumped into* the same cargo space. Before new loads of oil are taken on, the ballast water (polluted with oil) *is pumped* overboard. *Tank washing* in open seas often takes place.

The contribution of ballast water to the *dissemination* of aquatic organisms is very great. Ten billion tons of water are transported in ships' ballast tanks every year, and they contain 7,000 species of hydrocoles (Dynamics of marine ecosystems 2007). The fact has been established that for the world ocean, successful invasion via ballast waters of 851 species has occurred (Zvyagintsev et al. 2009). The *most dramatic examples* of the consequences these invasions are considered in Sect. 5.11.2 and 5.11.4.

The *second* place goes to bunkering operations and bilge water dumping, which provide 23% of oil product pollution. *Bunkering* includes the reception, transfer, storage, and transportation of oil products to the accepting ship. *Bilge water* is accumulated in a ship's engine room. As collecting bins are filled, the water is discharged overboard in most cases.

Photo 12.16 Water transport has negative impacts mainly on surface waters. The accident of the Liberian tanker *Argo Merchant* 29 miles southeast of Nantucket Island, Massachusetts, is shown. The tanker went aground on 15 December 1976. The oil spill began on 21 December 1976 and lasted until 12 February 1977. Altogether, more than 29,000 ton of oil entered the water. Ship accidents contribute to 14% of oil pollution (Photo credit: National Oceanic and Atmospheric Administration, January 1997)

The *third* place goes to ship accidents, which provide 14% of oil pollution (Khristenko 1983). The *reasons* for accidents can be grounding, collisions, navigation equipment malfunctions, damage at moorages, engine breakdowns, fires, and explosions. *Atmospheric* pollution is considerable during *fires* in tankers.

A continuous film of oil with an area of 2.6 km^2 is produced after a spill of 1 ton of oil (Zuyev 1999). After oil gets into the water, it ends its existence as a substrate very quickly. Only about 1–3% (sometimes up to 15%) on average of raw oil *dissolves* in the water, whereas from 10% to 40% *evaporates* (Korobov 2004).

The *length* of existence of oil patches on the surface of water depends on the following *factors*: (1) the volume of spilt oil; (2) its chemical composition; (3) weather and climate conditions; (4) temperature of the water; (5) type of circulation; etc. This period is from several hours to several months.

The movement of oil patches for long distances is possible. A patch is known to have travelled a distance of more than 200 miles over 50 days. The *speed* an oil patch travels is 3% of wind speed. When the density is high, a patch sinks until it reaches the bottom (Botvinkov et al. 2002).

Sea birds suffer greatly from oil spills. The oil pastes the feathers together, destroying their thermal insulation properties. The birds maintain body temperature by accelerating their metabolism, which leads to rapid depletion of depot fat and death from exhaustion (Petrichenko 2009).

When a bird tries to clean itself with its beak, it just moves the oil inside the feather layer. At the same time, oil enters the *digestive system*. Ducking birds mistake oil patches for food and are poisoned (Heinrich and Hergt 2003). In the case of a 'medium' oil spill, about 5,000 birds die; the wreck of the tanker *Exxon Valdez* near Alaska's shores killed about half a million birds (Belikov 2003).

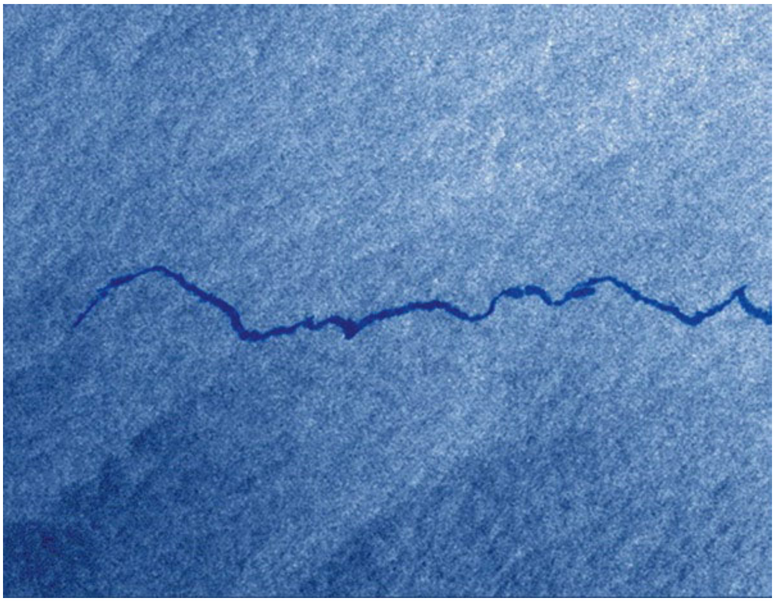

Photo 12.17 The dumping of ballast water from tankers is the most powerful source of impacts of water transport, providing more than 50% of oil pollution. Tank washing in open seas often takes place. A radio-locating image (in pseudo-colour) from the EPC-1 satellite shows a trace formed after a ship due to illegal discharge of oily waste water in the Sea of Japan (Photo credit: European Space Agency)

Photo 12.18 The transportation of bulk cargo (iron ore, grain, coal, phosphates, and bauxites) comprises more than half of the traffic of dry cargo. Pollution of the atmosphere due to emissions of dust during loading, transportation, and unloading of bulked cargo is unavoidable. Then, pollution of surface waters occurs, which influences hydrobionts. The photo shows a hopper barge transporting coal (Photo credit: Rob Loftis, 28 May 2007)

Photo 12.19 A typical technological operation of water transport is anchorage of ships. When this operation is executed, bottom deposits are disturbed, making the water turbid and resulting in the deterioration of the hydrobionts' living environment; photosynthetic activity is degraded, water is contaminated, and other events occur. The ship's anchorage causes maximum damage to coral reefs. The photo shows a ship's anchor after it damaged a coral reef near the coast of Florida (United States) (Photo credit: National Oceanic and Atmospheric Administration, 1997)

Photo 12.20 Atmospheric pollution is considerable during fires in tankers. The photo shows a fire on the Cypriot tanker *Haven* on 11 April 1991, near the coast of Genoa, Italy. It was unloading a cargo of 230,000 ton of crude oil. There was an awful explosion. As the fire engulfed the ship, flames rose 100 m high, and after a series of further explosions occurred, between 30,000 and 40,000 ton of oil poured into the sea. On 14 April, the 250 m long main body sank a mile and a half from the coast, between Arenzano and Varazze. For the next 12 years, the Mediterranean coast of Italy and France was polluted, especially around Genoa and southern France (Photo credit: Paolo Vaccari, Greenpeace International, 13 April 1991)

Photo 12.21 The contribution of ballast water to the dissemination of aquatic organisms is great. Ten billion tons of water are transported in ships' ballast tanks every year, and they contain 7,000 species of hydrocoles. The fact has been established that for the world ocean, successful invasion via ballast waters of 851 species has occurred. The photo shows a ship pumping ballast water (Photo credit: U.S. Coast Guard, 20 April 2008)

The *negative impacts* of oil patches on *plankton* are caused by the following *factors* (Ehrhardt and Seguin 1984): (1) gas exchange between the ocean and the atmosphere is blocked; (2) sunlight is prevented from reaching the water mass; and (3) favourable conditions for bacterial development are created, as hydrocarbons are a growth medium for many species.

Hydrocarbon pollution also has negative impacts on *zooplankton*. Its destruction causes decreases in the numbers of fish and cetaceans (Ehrhardt and Seguin 1984). *Marine mammals* die because they lose thermal insulation in their pelage when they come into contact with oil.

Evaporation of oil products contributes considerably to atmospheric pollution at the stages of transportation. According to S.I. Khristenko (1983), up to 0.75% of transported oil products evaporate during transportation and associated activities (0.14% at the loading stage, 0.48% during transportation, and 0.13% at the unloading stage).

A great number of goods that are transported by dry cargo ships are substances capable of emitting noxious gases or vapours or of combining with other substances to generate compounds which have pernicious effects on the environment. For example, when mineral *fertilizers* are transported, ammonia and fluorine evaporate. Fertilizers consume *oxygen* in water, leading to the deaths of hydrocoles and contributing to so-called water 'bloom' (reproduction of bacteria and plankton).

The environmental pollution that occurs during *transfer operations* is not great (for example, its share in pollution by oil products is only thousandths of a percent). During loading and unloading of bulked cargo, *atmospheric* pollution occurs because of spills and emissions of dust, and then water becomes polluted.

The running of ships' *engines* contributes to *atmospheric* pollution. It is believed that about 2% of the fuel is not consumed during engine operation.

As for the creation and functioning of water transport *infrastructure*, its impacts on environmental components vary. The building of *ports* in river outlets can cause the invasion of seawater, which affects the *freshwater flora* and *fauna*. *Channel* building leads to effects such as increases in *groundwater* levels, changes in *plant* species composition, salinization of *soils*, changes in the habitat conditions of various animals, and impacts on *microclimate*.

Channel dredging causes increases in water turbidity and, consequently, decreases in light penetration and photosynthetic activity (Environmental assessment sourcebook 1994). Redistribution of particles of alluvium leads to increases in the concentrations of toxic components and decreases in *oxygen content* in water. The transformation of bottom relief causes changes in water circulation, destruction of ecotopes of aquatic *fauna,* and reductions in species diversity. Moving dredged material to land leads to *land* withdrawal, and pollution of ground and surface *waters*.

The impacts of water transport upon the environment are illustrated by Photos 12.16 –12.21.

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Other Kinds of Activity

13

Abstract

Sections were chosen for this chapter based on the 'leftover' principle. The types of activities described are very different. Some of them are based on the development and use of biological natural resources (fisheries, aquaculture, hunting); others can be categorized as social activities. Engaging in social activities does not create any material products. These activities include recreational activities, sports activities, health services, and ritual activities. Water transfer does not create the products themselves; nevertheless, this type of supplemental activity ensures the possibility of production manufacturing. The types of activities discussed can be grouped based on 'age'. The most ancient ones are fisheries, hunting, and ritual activities; some time later, military activities and health services appeared. Then, possibly, housing and communal services, recreational activities, sports activities, and aquaculture were introduced. The most recently developed activity is, undoubtedly, space exploration. The importance of some activities is either declining (fisheries, hunting) or rising (aquaculture, recreational activities, sports activities, space exploration).

13.1 Fisheries

Despite the name, the targets of *fisheries* include not only fish but also other sea animals, invertebrates, and algae. In 2006, 81.9 million tons were harvested in seas and 10.1 million tons, in inland waters (State of world fisheries 2009). Several *species* form the *major part* of the catch: herring, cod, anchovies, tuna, flounder, mullet, squid, shrimp, salmon, crabs, lobsters, oysters, and scallops (http://en.wikipedia.org/wiki/Fishery). Areas of world fisheries are shown in Fig. 13.1.

Fishing gear is divided into *active* (moving in water) and *passive* (stationary). It is categorized based on *function* as follows (Ecological encyclopaedia 1999): (1) filtering gear (trail net; seine net – shore seine, ring seine, purse seine, dredge, etc.); (2) enmeshing gear (drift net, stationary net, stationary seine); and (3) hook gear (trolling, hook longlines, etc.).

There is also a method of catching fish that uses *pumps*. Light, electricity, and chemicals are used to attract aquatic animals to the fishing gear. Individual fishermen also use gigs, chemicals, and explosives (Jenings and Kaiser 1998).

If all the fish in the sea were evenly distributed throughout the oceans, fisheries would have been economically inefficient. However, the *productivity* of different parts of the ocean differs considerably. For example, *upwelling zones* (see Sect. 4.14) occupy 0.1% of the world ocean and provide a half of all fish catch (Gill 1986, vol 2). To increase the effectiveness of the harvesting, *fishery scouting* is conducted to

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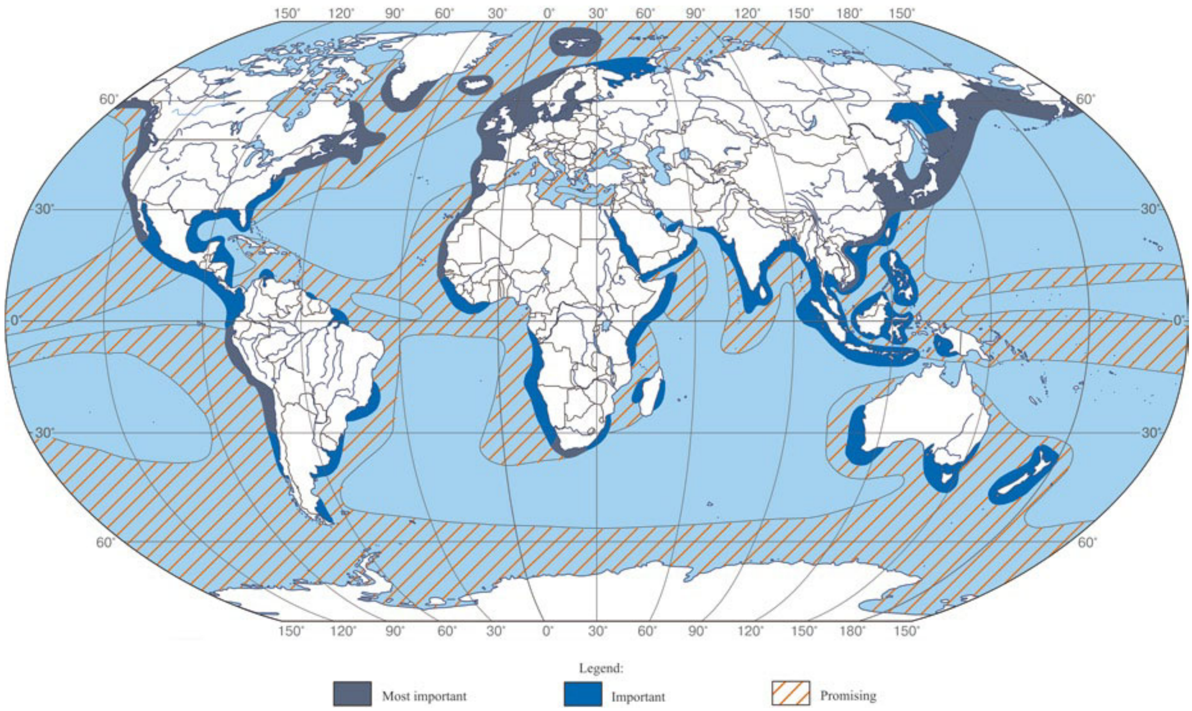

Fig. 13.1 Areas of World fisheries (Maksakovsky 2006, vol 1. Reproduced with permission of V.P. Maksakovsky)

Photo 13.1 Of the impacts of fishing activities, the by-catch has the strongest influence on the environment. It is known that usually, besides the fishery object, other species are caught. In catching fish, the presence of other species in the haul is unavoidable. The photo shows a diver freeing a sunfish caught in a Japanese drift net in the Tasman Sea (Photo credit: Roger Grace, Greenpeace International)

locate the fishing object concentrations and determine their migration routes. *Search equipment* includes echo-sounders, sonar, sound locators, underwater cameras, and other devices (Laptev 1988).

The *by-catch* has the strongest influence on the environment. It is known that usually, besides the fishery object, other species are caught. The percentages of the desirable and undesirable catches depend on

Photo 13.2 Marine bird fatalities occur mainly when they get tangled in fishing gear or get hooked when swallowing the bait. In many cases, the deaths of the adults lead to the deaths of the eggs or chicks. The photo shows tufted puffins entrapped in drift nets within the coastal waters of the Kuril Islands (Russia) (Photo credit: V. Kantor, Greenpeace Russia, June 2000)

many factors and vary greatly. On average, the by-catch comprises 33% of the total catch around the world (Norinov 2004), but sometimes, it exceeds the amount of the target object harvested by several times. For example, there are 3,000 ton of by-catch for every 500 ton of prawns in Australia; these are mainly crustaceans and echinoderms (Dayton et al. 1995).

The *by-catch* can *include* (1) fish; (2) mammals; (3) reptiles; (4) birds; and (5) different seabed biota.

In catching *fish***,** the presence of other species in the haul is unavoidable. Usually, these species are less valuable, and they are either thrown back into the sea or reprocessed (usually for fish flour production). For instance, the *swordfish* yield in the north-west part of the Atlantic has more *sharks* than the fishery object itself. In turn, when sharks are caught off the coast of Australia, the biggest share of the by-catch belongs to *skates* (Dayton et al. 1995).

Mammals are often found in the by-catch. For example, the number of *whales* that die when accidentally caught exceeds the number of whales caught intentionally (Rudsky and Sturman 2006). The presence of *dolphins* in the by-catch during fishing for salmon was a serious problem. It is believed that six million dolphins were killed this way (For saving of dolphins 2007). In the Pacific, *porpoises* were often caught in purse seines, and the total number that died is also estimated at six million (Dayton et al. 1995).

Reptiles in the by-catch are mostly represented by *turtles*. For instance, in the southern part of the United States and adjacent regions of Mexico, the *diamond-back Malaclemys terrapin* is widespread. Also, the *blue crab*, *Callinectes sapidus*, is common in this area and is a fisheries target. The crabs are caught with container traps dug into the sea floor. However, the turtles are also often trapped in them as well. Because of this, 88,000 turtles die annually in the state of New Jersey (United States) (Semenov 2008).

The main reasons for marine *bird* fatalities (albatross, tufted puffin, etc.) are getting tangled in the fishing gear or getting hooked when swallowing the bait. In many cases, the deaths of the adults lead to the deaths of the eggs or chicks. After the death of the breeding partner, a new couple is usually formed after a long delay (Klaer and Polacheck 1998; Brothers et al. 1999).

Seabed biota (*echinoderms*, *polychaetes*, *molluscs*, *sponges*, *crustaceans*, etc.) are in the by-catch of trails, dredges, and traps, which are installed on the bottom or dragged along it. For example, during trawler fishing in the Barents Sea, the amount of sponges and *Cucumaria* caught at one time sometimes reaches several tons. When *Cucumaria* are caught by trails in winter, it is lethal for them. Sponges often get seriously damaged and do not survive after they have been returned to the water (Dynamics of marine ecosystems 2007).

The second important consequence of fishery is *habitat deterioration*. Much fishing gear is dragged along the sea bottom, damaging algae fields in particular. For instance, during trawler fishing next to the south-east coast of Spain, 45% of the *Posidoma* meadows were damaged. Thus, the risks of juveniles being exposed to predators rise (Jenings and Kaiser 1998). Removal of seabed biota (sponges, hydroids, bryozoans, amphipod tubes, etc.) can also result in habitat deterioration (Turner et al. 1999).

Photo 13.3 Seabed biota (echinoderms, polychaetes, molluscs, sponges, crustaceans, etc.) are found in the by-catch of trails, dredges, and traps, which are installed on the bottom or dragged along it. The photo shows sponges found in a trawl net after a fish trawl survey in Spirits Bay at the northern tip of New Zealand (Photo credit: New Zealand Ministry of Fisheries, 1989)

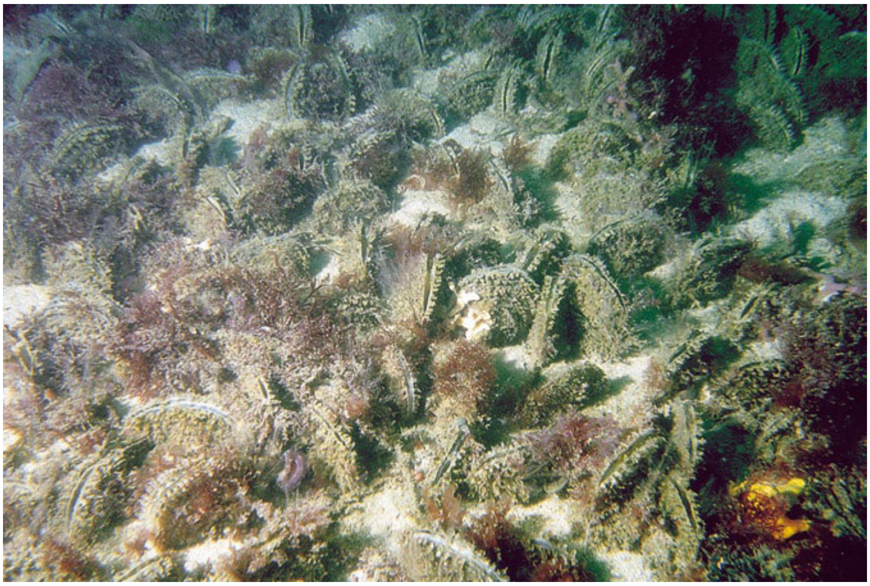

Photo 13.4 The other important consequence of fishery is habitat deterioration. Much fishing gear is dragged along the sea bottom, damaging algae fields, removing seabed biota (sponges, hydroids, bryozoans, amphipod tubes), and causing other impacts. The photo shows the bottom near Otama Beach on the Coromandel Peninsula, New Zealand, before dredging (Photo credit: S. Thrush, National Institute of Water and Atmospheric Research, Hamilton, New Zealand, 1997)

Photo 13.5 This photo illustrates the area of the sea bottom shown in Photo 13.4 (depth is 16–18 m), but after dredging operations (Photo credit: S. Thrush, National Institute of Water and Atmospheric Research, Hamilton, New Zealand, 1997)

Indirect impacts include changes in the numbers of prey organisms available to predators; changes in the numbers of predators, which take out the prey; and influences on interspecies competition intensity. For instance, the diet of many seabirds and mammals is restricted to a very limited number of fish species, and decreases in ichthyofauna stock (as a result of fishery) will immediately reflect on their reproduction and abundance.

In just these ways, fishery has significant environmental implications. Impacts are the *greatest* in equatorial reefs, on solid substrates in temperate waters, and in the depths. The influence on communities of sandy bottoms on shallow shelves is *insignificant* by comparison because they have already adapted to constant movement and mudding (Jenings and Kaiser 1998).

The impacts of fisheries on the environment are shown in Photos 13.1–13.5.

13.2 Aquaculture

Aquaculture is the breeding and raising of hydrobionts in conditions controlled by humans. Though it is a very ancient activity (the indigenous Gunditjmara people in Victoria, Australia, may have raised eels as early as 6000 BC), this field developed mainly in the twentieth century. In 2007, 443 species of hydrobionts were cultivated; of these, 430 had been cultivated since 1900 (http://www.ehow.com/aquaculture/).

The main *groups* grown in culture are fish, molluscs, crustaceans, echinoderms, and algae. The share of aquaculture in the global supply of fish and seafood grows constantly. Thus, while in 1970, the share of aquaculture in the total volume of sea products was 3.9%, by 2006, its contribution had grown to 36%, and its volume, up to 51.7 million tons, or US$78.8 billion in economic terms. The major part (61%) of aquaculture – fish, crustaceans, and molluscs – are grown in inland waters (ftp://ftp.fao.org/docrep/fao/011/i0250r/i0250r01.pdf).

Aquaculture has the following *types of impact* on the environment: (1) resources consumption; (2) emission of chemicals from construction materials; and (3) influences on ecosystems (Iwama 1991).

Resources consumption means that for feeding hydrobionts, fish flour and fish oil (made of 'free-living' fish) are used; as a result, the amounts of wild fish that are consumed exceed the amounts of fish that are produced.

For example, to obtain 1 kg of *salmon*, it is necessary to use 3–5 kg of fish living in natural conditions. In 1985–1995, *shrimp* farmers used 36 million tons of

Photo 13.6 Aquaculture, first of all, has influences on the aquatic environment. These effects consist mainly of water pollution with different substances (organic substances, antibiotics, hormones, growth stimulators, and pesticides). The photo shows houseboat rafts with cages under for rearing fish on a fish farm near My Tho, Mekong Delta, Vietnam (Photo credit: Bill Bradley)

wild fish to produce just 7.2 million tons of shrimp. Fish flour is usually made of pelagic species (menhaden, mackerel, etc.), which are not usually used for food. Besides, fish flour is made of *by-catch*, which has been thrown out as waste. However, this fish flour could have been used in poultry or pig farming (Emerson 2000).

Chemicals introduced into the water by construction materials include heavy metals, plastic additives (stabilizers, pigments, antioxidants, flame retardants, fungicides, etc.), and antifoulants (e.g. tributyltin, antiseptics). Many of these chemicals are toxic to fish, though their low solubility and low rates of leaching and diluting ensure some protection (Reducing environmental impacts 1991).

Aquatic culture has *environmental impacts* on the following natural *components*: (1) surface waters; (2) flora; (3) fauna; (4) soils; and (5) the atmosphere. Apart from that, social impacts also take place.

The influences on the *aquatic environment* are more typical, and they occur in the farming of all types of hydrobionts. These effects consist mainly of *water pollution* with different substances. For instance, artificial granulated nutrition is used for feeding many fish species. Food spreads all over the water surface and is eaten by fish during its sedimentation (people can observe this effect in aquariums). Even in a well-balanced feeding process, 30% of the nutrition is not consumed. It reaches the bottom, where it is utilized by benthos or is degraded by microorganisms (Boyd and Clay 1998).

Photo 13.7 Overcrowding of fish creates ideal conditions for infections or parasitic invasions. Salmon lice are a typical example. The infected fish become sick, and their resistance is low. The photo shows sea lice on salmon in Norway (Photo credit: http://en.wikipedia.org/wiki/Sea_louse)

In Scotland, approximately 50,000 ton per year of unpurified sewage water from *salmon* farms is dumped into the sea. The sewage contains suspended organic substances and dissolved matter such as nitrogen,

Photo 13.8 Dumping from aquaculture facilities leads to eutrophication of the surface waters. The main materials launching the process are nitrogen and phosphorus. The picture shows fish ponds in the Taihu Lake area of Jiangsu province (China). The arm connecting the lake with the Grand Canal supplies water to numerous small-sized man-made ponds used in aquaculture (Photo credit: H. Zhang, Food and Agriculture Organization of the United Nations, photo 20044, 14 May 1997)

phosphorus, and carbon, which is present because of excessive nutrition, turds, and kidney and gill secretions. Those emissions are equivalent to 75% of the *residential sewage* of the population of Scotland (Emerson 2000; Tovar et al. 2000a).

Dumping from aquaculture facilities leads to *eutrophication* of the surface waters. The main materials launching the process are nitrogen and phosphorus. In the state of Alabama (United States), nitrogen exhaust per ton of channel catfish, *Ictalurus punctatus*, was 9.2 kg, and phosphorus exhaust is 0.57 kg/t. For Swedish fish-breeding facilities, the respective figures are 61 kg of nitrogen and 2.2 kg of phosphorus (Tovar et al. 2000b). The nitrogen emission for every ton of aquaculture product from the Black Sea coast of Russia is 65 kg; 12 kg of phosphorus and 500 kg of organic substances are also produced (Fashchuk and Muravyev 2007).

The eutrophication of the water creates conditions for algal blooms (see Subsection 5.10.1, on poisonous aquatic plants), which produce toxins. When an algal bloom is over, the algae settle on the bottom, where their decay leads to declines in *dissolved oxygen* (Boyd and Clay 1998; Emerson 2000).

Other pollutants resulting from aquaculture include antibiotics, hormones, growth stimulators, and pesticides. *Antibiotics* are added to the food to prevent diseases. It is believed that 20–30% of the antibiotics is consumed by the fish; the rest, 70–80%, pollutes the water (Reducing environmental impacts 1991). *Hormones* and *growth stimulators* are used to change the gender, productive capacity, and growth of the cultivated organisms. Their environmental impacts have not yet been studied sufficiently to draw any conclusions as to their effects.

Pesticides are used for pest control. For example, at fish farms in Norway in 1989, 3,488 kg of dichlorvos was used to prevent salmon louse infection. Such agents have clear negative impacts on the environment; thus, their use must be strictly limited (Reducing environmental impacts 1991).

The impacts on *fauna* have many forms. *First*, a lot of wild fish are used to feed fish in culture. *Second*, the grown fish often escape. Different scenarios are possible if fish escape. Escapees can win the competition with the local species at first, but then, their numbers may drop or the offspring resulting from interbreeding may be poorly adapted to the ecosystem (Bailly and Paquotte 1996).

Cases of infections or parasitic *invasions* of wild fish are frequent. *Salmon lice* is a typical example. This is a species of cladocerans whose adults live on the skin and gills of salmon and eat skin coverings. The infected fish become sick, and their resistance is low. Mortality among juveniles caused by this parasite is much higher. But in nature, the young fish are separated from the adults, so the fingerlings returning to the sea have a slim chance of meeting adults and getting infected.

Overcrowding of fish creates ideal conditions for the breeding of lice. If there are salmon farms on the routes fingerlings take through estuaries or bays, the parasites enter the nearby waters and infect the juveniles. At the Pacific coast of Canada, the infection rate of juveniles in natural conditions does not exceed 5%. Next to fish farms, it increases dramatically, which leads to *five times the mortality rate* (Naymark 2007).

It is known that the transportation of prawns leads to the dissemination of pathogens (Phillips et al. 1993). Viral diseases originating at prawn farms have been noted in China, Thailand, India, and Ecuador (Boyd and Clay 1998).

The destruction of mangrove forests for building aquaculture facilities (mostly prawn farms) has effects on *vegetation*. An estimated 10% of mangrove forests worldwide have been lost because of this (Boyd and Clay 1998). Ammonia emissions have impacts on the *atmosphere*. For instance, in the United States, annual emissions of this gas from *channel catfish*, *Ictalurus punctatus*, breeding ponds (which have a total area of 66,000 ha) are estimated to be 1,548 ton (Gross et al. 1999).

The *social impacts* of aquaculture consist of the limitation of free access to the seashore and decreases in its recreational value (swimming, sailing, windsurfing, and other activities); the aesthetic characteristics of the shoreline also are changed (Bailly and Paquotte 1996).

The influences of aquaculture on the environment are illustrated by Photos 13.6–13.8.

13.3 Hunting

Hunting is one of the most ancient human activities. In the beginning, hunting techniques (both tools and methods) were primitive. Gradually, they became more complicated and advanced (spears, arches with arrows, darts, missiles, traps, nets, snares, etc.).

Contemporary tools for hunting wild animals can be divided into two *groups* (Dementyev 1971): (1) tools for *active hunting* (the presence of the hunter and his actions are necessary at the moment of the bird or animal kill) and (2) *self-activating tools* for hunting (the catch usually happens without the presence of the hunter).

The *first* group includes (1) gun hunting; (2) use of hunting animals (predacious birds, greyhounds, ferrets, domesticated cheetahs); and (3) nets. The *second* group includes (1) steel traps (squeezing and jamming); (2) falling traps (jaws, billets, sable traps); (3) snares and nooses; (4) live trapping; and (5) nets (Gusev 2001).

From the social point of view, *two groups* of hunters can be identified: (1) professionals and (2) amateurs. The *first group* includes people for whom hunting is the main source of food or a living. Hunters in this category are most numerous in the developing countries of Africa, Asia, and Latin America. The *second group*, on the contrary, is more common in the developed countries. For example, in the United States, 9.4% of the country's population are hunters; for Finland, this figure is 6.4%, and for Norway, it is 6.0% (Rogachev 2000).

At the present time, the *importance* of this type of activity is the *greatest* in five countries of the Congo River basin. The meat of wild animals is a main source of animal protein, and hunting provides the greatest share of income for families living in forests (Wilkie and Carpenter 1999). This situation is most typical for Gabon and Cameroon (Fa et al. 2003).

Research has shown that the *importance of hunting* is lower in other regions of tropical rainforests. For instance, during 1 year, the count of killed animals brought to 24 (Amazon) and 14 (Congo) villages showed that the rate of withdrawal of wild mammals with masses more than 10 kg was 177.7 kg/km^2 a year for the Congo basin, whereas for the Amazon basin, this number was just 3.69 kg/km^2 (Fa et al. 2002).

Photo 13.9 Market hunting – mass hunting of game birds for the dinner table and restaurant trade – pushed several species of waterfowl to the brink of extinction during the late 1800s and early 1900s. The results of hunting for wild ducks in California (United States) are illustrated (Photo credit: U.S. Fish and Wildlife Service, middle 1930s)

This type of activity *influences mainly* vegetation and the animal world. The impact became noticeable after man had mastered *fire* in the end of the Paleolithic Age. At the same time that ‘fire technology’ appeared, forests and other vegetation were burnt down during hunting.

At that time (more than 100,000 years ago), *systematic burning of forests* used as a ‘*universal hunting tool*’ led to considerable environmental disturbance, provoking degradation of ecosystems and decreasing the quantity and quality of biological resources (Ramad 1981). It is presumed that habitat degradation contributed to the extinction of some animal species. Plant successions led from forests to savannas, steppe, and shrubs, and the climate was changing. Vast areas were turned into *pyrogenic landscapes* subjected to erosion, desertification, and phreatic decline (Govorushko 2008a; Human occupies Mother Earth 1997).

Sometimes, excessively intense hunting was causing population densities to fall down to critical levels, when regular (during mating season) meetings of animals of different genders were becoming improbable, thus leading to *species extinction* (Laptev 1981).

Though habitat conversion is largely to blame in this process, since AD 1600, many cases of extinction have been recorded as a result of overhunting (Bodmer et al. 1997; Rowcliffe et al. 2003). Overexploitation of hunting resources is possible even if primitive hunting tools are used, for example, snares (Noss 1998a) and self-activated nets (Noss 1998b). The scale of hunting can

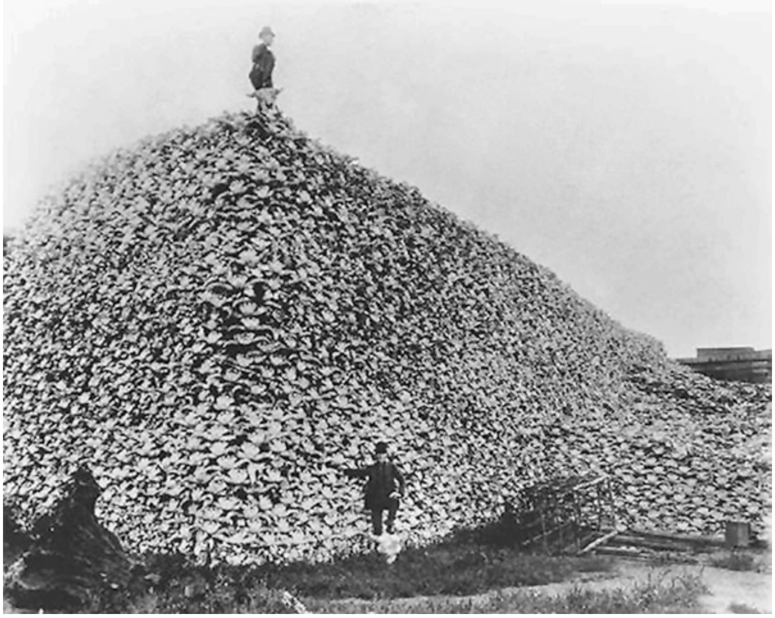

Photo 13.10 The American bison (*Bison bison*) was also on the verge of extinction. This species was extremely numerous. In the nineteenth century, however, advanced hunting technology (rifles) and distribution technology (carts, wagons, and trains) allowed for the massive slaughter of bison. Thankfully, efforts of environmentalists, the U.S. government, and private landowners came together to save this species. The photograph shows a pile of American bison skulls waiting to be ground for fertilizer (Photo credit: Burton Historical Collection, Detroit Public Library, mid-1870s)

Photo 13.11 'Fire technology', which consisted of burning out forests and other vegetation in the course of hunting, came into use more than a hundred thousand years ago. The systematic use of fires as a 'universal tool of hunting' resulted in sizeable environmental consequences. Now, the scales of such activities are much less, but they still occur in some places. The photo shows an artificial fire in the Central African Republic for the purpose of hunting foe rodents (Photo credit: R. Faidutti, Food and Agriculture Organization of the United Nations, image 14185, 1987)

be characterized by the figure five million tons, which is the *amount of meat* obtained by the villagers in African and Latin American tropical forests (Fa et al. 2002).

The story of the *American passenger pigeon, Ectopistes migratorius*, is well known. It was an extremely numerous species; in 1810, their number was estimated to be two billion birds in just one of the flocks (Riklefs 1979). Nevertheless, intense hunting for their delicious meat (in the state of Michigan [United States] alone in 1879, one billion pigeons were caught) resulted in their extinction. The last passenger pigeon died in a zoological garden in Cincinnati in 1879 (Sedlag 1975).

Now, in the United States, hunting is mainly a leisure activity. Two hundred million animals are killed there annually, including 42 million *mourning doves*, 30 million *squirrels*, 28 million *quail*, 25 million *rabbits*, 20 million *pheasants*, 14 million *ducks*, six million *deer*, and many other animals (http://www.idausa.org/facts/hunting.html).

The environmental impacts of animal withdrawal are ambiguous. Limited hunting has *positive influences* on animal populations because it prevents land degradation and resources depletion by creating optimal population densities. It also prevents animal migrations and stops or limits pandemics that appear due to overcrowding (Conover 2001).

Hunting often influences the *sex–age structure* of animal populations. Very often during hunting, preference is given to individuals with certain characteristics (e.g. males with big horns or females with tender meat). Selective killing very often results in negative environmental outcomes (Cullen et al. 2001).

Indirect effects of hunting on animals also take place. Aquatic birds swallow lead pellets, mistaking them for gravel and seeds. In the state of Oregon (United States), pellets were found in the stomachs of 40.2% of wild ducks, 40.4% of pintails, and 13.7% of widgeons. In North America, 630,000 wild ducks die because of lead poisoning every year. The numbers of pellets per hectare can reach 100,000 in a 9 mm layer of bottom deposits (Laptev 1981).

There are cases of *white crane*, *Grus leucogeranus*, fatalities in Yakutia, Russia (Pshennikov et al. 2001). The numbers of deaths of aquatic birds depend greatly on soil composition. For example, in muddy bottom deposits, the pellets quickly sink, becoming unavailable and decreasing the risks of the birds swallowing them (Chernishev at al. 2007).

Impacts on *vegetation* take different forms. For example, selective killing can influence the populations of some plant pests (Wright 2003). The hunting of certain animal species can lead to long-term changes in tropical forest dynamics because of the loss of *seed dispersers*, large *granivores*, *frugivores*, and '*habitat landscapers*' such as large forest mammals (Fa et al. 2002).

Hunting is the reason for many *accidents*. In the United States in 1988, for instance, hunters killed 177 people and injured 1,719; very often, the victims were just tourists or people on their own land (http://www.idausa.org/facts/hunting.html). The majority of cases took place during the pursuit of game, although guns sometimes accidentally go off during transport or when they are carelessly handled (Hartwig 2000).

The impacts of hunting on the environment are shown in Photos 13.9–13.11.

13.4 Water Transfers

By the term *water transfers*, we mean the process of water withdrawal from one source (river, reservoir, lake, etc.) and its further transportation by riverbed, channel, tunnel, or pipeline to consumers.

One can *subdivide* such water transportation into transfers for water supplies, providing navigation, hydropower engineering, irrigated farming, and drainage of over-humid lands. The channel that connected the Tigris River and the Euphrates River was dug in about 2400 BC and became one of the *earliest examples* of channel building. It was dug for the purpose of irrigating fields since water rise in the Tigris River did not coincide with that in the Euphrates River (Anderson and Trigg 1981).

The *volume* of transported water and the *distance* it is transported are the crucial parameters of river flow transportation systems. The most widespread *index to estimate the scale* of river flow modification is calculated as the product of the annual river flow transported (cubic kilometres per year) times the distance it is transported (kilometres).

Presently, most river flow transfers are carried out for *irrigation* needs and are classified as small or

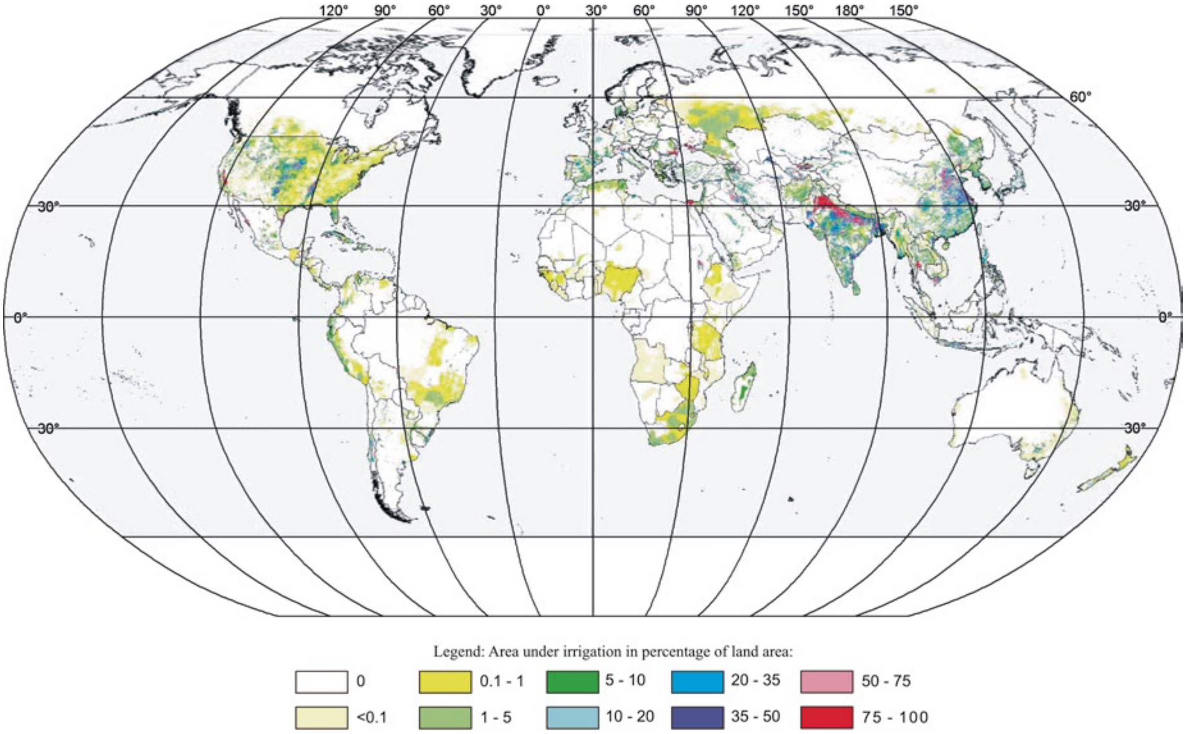

Fig. 13.2 Distribution of areas under irrigation in the world, 2000 (Water: a shared responsibility 2006) (Reproduced with permission of Food and Agriculture Organization of United Nations)

average (up to 1,000 km^3/year). So far, the *Karakum Channel* in Turkmenistan remains the largest channel, judging by this index. It transports 11 km^3/year over a distance of 1,100 km (Govorushko 2009c). Still, creation of a *new channel in China* has already started. This channel will transfer 44.8 km^3/year over a distance of 1,300 km from the Yangtze River to the northern Chinese plain (Govorushko 2005). The global distribution of areas under irrigation is shown in Fig. 13.2.

In describing water transfers, it is necessary to distinguish three *zones,* which differ from each other in the impacts made upon natural habitat: (1) zone of water withdrawal; (2) zone of water transportation; and (3) zone of water usage. Environmental impacts in these zones are as follows (Shiklomanov and Markova 1987).

The zone of *withdrawal* is characterized by decreases in river flow, drops in water levels, intensification of riverbed processes, diminution of waterlogged sites, greater penetration of salty seawater, and other effects. The zone of *transportation* is characterized by increases in river flow, rises in water levels, underflooding and waterlogging of nearby lands, intensification of erosion and evaporation, and other impacts. The zone of *water usage* is characterized by intensification of erosion and evaporation, worsening of surface water quality, and so on.

There have been cases when river flow has been almost *completely taken away* in the zone of withdrawal. One may cite as an example the *Colorado River*, which stopped flowing into the Gulf of California, since water was used to irrigate fields in the United States and Mexico (Rosenberg et al. 2000). The *Syr Darya River* and the *Amu Darya River* did not reach the Aral Sea in drier years (e.g. 1980 and 1985) (Sempere-Antuan 2000). Decreases in the *Jordan River* flow caused levels in the Dead Sea to drop (Goudie 1997).

Photo 13.12 Presently, most river flow transfers are carried out for irrigation needs. The major way of supplying water to fields is surface irrigation with water distributed under gravity. The photo shows irrigated land in Mexico (Photo credit: F. Bequette, United Nations Educational, Scientific and Cultural Organization)

Photo 13.13 Water delivery through sprinkling irrigation is more economical so far as water consumption goes, but due to the initial expense, it is used more rarely. Sprinkling of seeds in Arizona (United States) is shown (Photo credit: Jeff Vanuga, U.S. Department of Agriculture Natural Resources Conservation Service)

Photo 13.14 The most economical (and most expensive initially) method of water delivery to plants is drip irrigation. The photo illustrates a drip irrigation system used on vineyards in Rio Arriba County, New Mexico (Photo credit: Jeff Vanuga, U.S. Department of Agriculture Natural Resources Conservation Service, 2002)

Measures aimed at decreasing water loss in the zone of transportation are very important. Quite often, sizeable volumes of transported water are lost because of *ground leakage*. Thus, in the first years after the Karakum Channel was created, 3 km^3/year (out of 11) were lost in that manner; nowadays, those losses have been reduced to 1 km^3/year due to silting where the leakage occurred (Govorushko 2009a).

All together, more than 2,200 channels with a total length of 170,000 km have been built in the basin of the Aral Sea; but for all that, no measures to mitigate filtration have been taken in most cases (Stadnitsky and Rodionov 1996). *Water losses* in irrigation systems in Pakistan amount to 55–65% (Shiklomanov and Markova 1987).

In the zone of water usage, river flow increases considerably. Thus, the annual river flow of the Burntwood River, which transports water to the Nelson River, increased from 3.3 to 27.3 km^3/year, or by 800% (Shiklomanov and Markova 1987). The *greatest river inflow transfers* are typical for Canada, the United States, India, and Turkmenistan (Govorushko 2007, 2008b).

Water transfer, apart from changing river flow, also influences *ichthyofauna* composition. Channels play roles of environmental pathways through which fish can migrate. For example, when the waters from Dnepr went through the North Crimea Channel (402 km long), Dnepr fish became usual for the Crimea – primarily low-value fish: *perch*, *ruff*, *tench*, and *silver bream* (Kozlov 1979).

Another negative result of water transfer is that *weeds* are spread. Detailed research on weeds spreading through the water of irrigation channels in the Vakhshskaya Valley in Tajikistan has shown how serious the problem is. For example, on one farm during 14 h, irrigation water brought in 955,000 seeds per hectare in July, two million seeds per hectare in August, and 3.9 million seeds per hectare in September (ten species were represented). The source of the seeds in irrigation water is the coppices of weeds at the banks of the channels (Nikitin 1983).

The impacts of water transfers on the environment are illustrated in Photos 13.12–13.15.

Photo 13.15 The water supply is another purpose of diversion of run-off. The Gezira main canal (Sudan) shown here is used by farmers for drinking water and fishing. Measures aimed at decreasing water loss in the zone of transportation are very important. Quite often, sizeable volumes of transported water are lost because of ground leakage (Photo credit: United Nations Environment Programme, *UNEP Sudan Post-Conflict Environmental Assessment* report, 27 June 2007)

13.5 Housing and Communal Services

Housing and *communal services*, apart from the built-up area, include the complex of enterprises and organizations of public services. These include sanitary enterprises (public water supplies, sewage facilities, saunas, laundries), removal and disposal of household wastes, energy facilities, communal construction (roads, bridges, etc.), hotels, chemical clothes cleaning enterprises, funeral bureaus, and others. The situation in relation to sanitation coverage is illustrated in Fig. 13.3.

At the present time, cities occupy 3% of the land on Earth (Modern global changes 2006, vol 1). The *proportion* of built-up area is greatest in small and densely populated countries of Western Europe (e.g. Denmark, Belgium, and the Netherlands), where they occupy 8–16% of the total land area (Gorshkov 1992).

The problem of *waste* is very complicated. About 400–450 million tons of solid waste is produced globally every year. Its volume is proportional to the economic development level of a country. In the developed world, for example, the amounts per capita are as follows (in kilograms per year): the United States, 803; Canada, 601; the Netherlands, 497; Japan, 408; Italy, 348; and Germany, 318 (Yanin 1998). In the developing countries, the amount of waste produced is much less, which explains why the average amount of waste per capita is 200 kg a year globally (Kazakova 2003).

The *composition* of household waste is specific to different regions. For instance, in Khabarovsk (Russia), it is as follows (in percent): paper and cardboard, 12; textiles, 8; polymeric materials, 15; leather and rubber, 10; glass, 9; construction waste, 10; metal, 10; wood, 7; food wastes, 17; and others, 2 (Ryzhuk and Mayorova 2006).

Housing and communal services influence the following natural *components* (Govorushko 1996): (1) atmosphere; (2) surface waters; (3) groundwater; (4) animal world; (5) geomorphologic environment; and (6) geological environment.

Significant *air pollution* results from burning waste, which contains the following elements (Savenko 1991): 0.5–0.7% nitrogen, 0.06–0.28% sulphur;

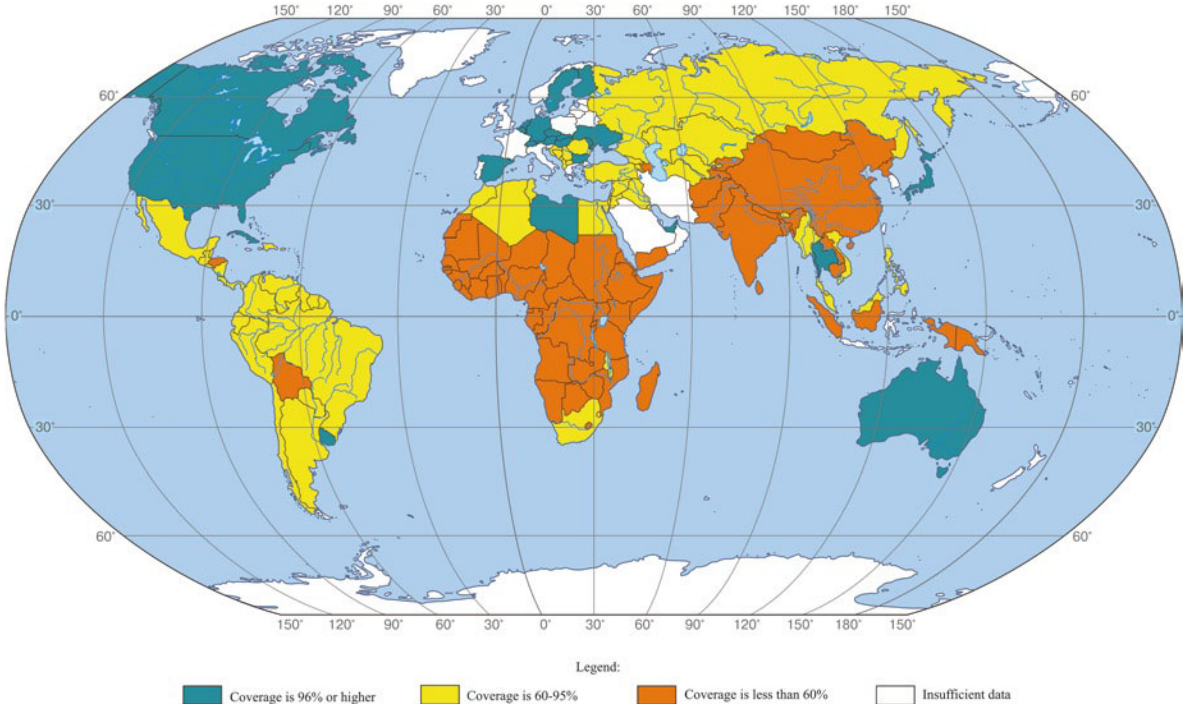

Fig. 13.3 The situation in relation to sanitation coverage, 2004 (http:// maps grida.no/go/graphic/the-situation-in-relation-to-a-drinking-water-and-b-sanitation-coverage-2004. Reproduced with permission of United Nation Environmental Program)

Photo 13.16 Since ancient times, humans have used underground space for living. At the earliest stage, they settled in the natural hollows and caves, and later, they began to actively transform the geomorphologic environment. The photo shows troglodyte (indigenous Berber inhabitants) dwellings in southern Tunisia. Their underground location allows the people to escape from the heat (Photo credit: S.S. Ganzey, Pacific Geographical Institute, Vladivostok, Russia, August 2008)

Photo 13.17 Pollution of surface waters by detergents – synthetic surface-active agents used for washing – is characteristic of many developing countries. Detergents are severe toxins that are difficult to remove, and they are almost non-biodegradable. The photo shows Mayan Indians washing laundry in a river in Guatemala (Photo credit: Barbara Theisen)

0.04–0.7% chlorine; and trace amounts of lead, nickel, copper, and zinc. Waste incineration plants emit carbon dioxide and carbon monoxide, as well as oxides of nitrogen and sulphur, ammonia, carbohydrates, hydrogen chloride, fluorine hydride, and highly toxic heavy metals. Thus, when 1 ton of domestic waste is burnt, the exhaust into the atmosphere contains 23 g of lead, 4 g of mercury, and 1.3 g of cadmium. Methane is released as a result of waste decay at landfills. Its emissions on a global scale are estimated to be 20–70 million tons a year (Modern global changes 2006, vol 1).

Every country has its own *sources* of emissions. In India, for example, *cremation fires* contribute considerably to atmospheric pollution because ten million dead people are burnt annually. For each cremation, funeral bureaus use 450 kg of wood. Annually, in India, 50 million trees are felled for this purpose. As a result, 50,000 ton of solid particles and 8,000 ton of carbon dioxide are emitted (Agarval 2008). In the United States, mercury pollution has a certain significance. Annually, 620 million fluorescent lamps are disposed of, and annual mercury emissions are estimated to be 2–4 ton (Aucott et al. 2003).

The most serious pollutants of *surface waters* are sewage and storm collection run-off. In the cities of the developing countries, human *faeces* are the most dangerous pollutant.

In the least developed countries, only one third of the houses have sewage systems, and water treatment plants are also absent (Environmental assessment sourcebook 1994). Only 209 out of 3,119 Indian cities have facilities for partial effluent treatment of sewage waters, and only 8 have full processing plants (Avvannavar and Mani 2008).

Housing and communal service waste in the developed countries contains 90% of the *detergents* – synthetic surface-active agents – used for washing. Detergents are severe toxins that are difficult to remove, and they are almost non-biodegradable. The total volume of sewage waters in the world reaches 450 km^3 a year.

The impact of *water supplies* is mostly in the withdrawal of great amounts of water. *Water loss* due to leakage, run-off from watering streets and lawns, air

Photo 13.18 About 400–450 million tons of solid domestic waste is produced globally every year. The photo shows a garbage dump in St. Petersburg, Russia (Photo credit: E. Usov, Greenpeace Russia, 16 May 2006)

Photo 13.19 Poor development of waste disposal systems is characteristic of most developing countries. The photo shows garbage in the bed of one of the rivers flowing through the city of Mumbai in India (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 3 November 2007)

conditioning, and for other reasons is also serious. In housing and communal services of the United States, water loss amounts to 24% (Bochkareva 1988).

Groundwater is affected by pollution. For example, chemical clothes cleaning enterprises often emit perchloroethylene, a chlorocarbon solvent (Mitasheva 1998). Changes in phreatic levels are typical. In some regions, they drop due to declines in water penetration capacity of the ground (soil thickening; waterproof coverings such as asphalt and concrete). In other cases, phreatic levels increase because of sewage waters and leakage from water pipes (Kovalevsky 1994).

One of the factors that influences the *animal world* is skyscrapers that are lit at night. Migrating birds head toward the light and crash into the glass facades of the buildings. In North America, from 100 million to a billion birds die due to such mishaps every year (Kiyver 2002).

Impacts on the *geomorphologic environment* are mainly due to relief changes caused by construction, landfills, etc. Buildings and construction have direct influences on the *geological environment* through their sheer weight and warming of the soil (e.g. thickening, thermal sagging, thermokarst, and thixotropic dilution).

Build-up of an area changes the *climate* considerably: For example, the levels of solar radiation drop; humidity, wind speed, and precipitation regimes change; and temperatures increase.

In just these ways, *all natural components* are more or less changed where residential areas are located. Environmental components are subjected to all kinds of influences, such as mechanical (static and dynamic), chemical, biochemical, electrical, and thermal effects (Likhacheva and Smirnova 1994). The most important factors are the problems of *waste disposal*, *water supplies,* and *power supplies*.

The impacts of housing and communal services on the environment are illustrated by Photos 13.16–13.19.

13.6 Recreational Activity

Recreational activity is usually defined as an activity aimed at rest and recovery of physical and mental resources. The *number of people* practicing it is comparable with the number of people in the world. In 2000, the number of tourists in the world (tourism is a part of recreational activity) was estimated to be 700 million people (Gosling 2002). Global recreational zoning is shown in Fig. 13.4.

Types of recreational activity include the following: (1) medical, based at stationary facilities having medicinal purposes (sanatoria, health resorts, etc.); (2) health-improving, engaged in at stationary facilities designed for recreation (preventative clinics, rest homes, campsites, etc.) and also non-organized; (3) sports, combined sports activities, hunting, and fishing, which can be both organized and non-organized; (4) tourism, connected with travels and backpacking; and (5) educational tourism to valuable natural, cultural, and historical objects (Geography of tourism 2009). Recreation often has a seasonal character.

To engage in these activities, people need *recreational resources*. These can be categorized as *follows* (Geoecological fundamentals of protection 1991; Rydsky and Sturman 2006): (1) natural (e.g. hydrological, climatic, forest, landscape, geological, hydrogeological, specially protected natural complexes); (2) balneological (mineral waters, therapeutic muds, etc.); and (3) architectural-historic (e.g. monuments of culture, history, archaeology).

Recreational activities have impacts on the following natural *components*: (1) geological environment; (2) soils; (3) vegetation; (4) animal world; and (5) surface and ground waters (Govorushko 1999). They also influence the social environment of a region.

Two *types* of recreational activity (rock climbing and speleology) are connected with mountains. They do not damage the *geological environment* considerably (Camp and Knight 1998). Searching for and collecting minerals, crystal formations, and fossils brings many more problems. One of the most dramatic examples of such activity is the Petrified Forest National Park in Arizona (United States), where souvenir hunters completely destroyed the cover of some fossil trees. The destruction of *stalactites* and *stalagmites* by speleologists is also typical.

Impacts on the *soil* include its thickening due to pedestrian, horse, or vehicle traffic (e.g. at campsites). *Horse transport* has especially devastating effects on soils (Deluca et al. 1998). Thickening of soils results in drainage distortions (provoking erosion) and insufficient aeration of plant roots and soil organisms.

Pedestrian movement also destroys grass, bushes, and undergrowth. The *consequences* of the pressure on *vegetation* are the following: (1) damage to plants; (2) stunting of growth; (3) thinning of leaf cover; and (4) vanishing of species with low productivity (Heinrich

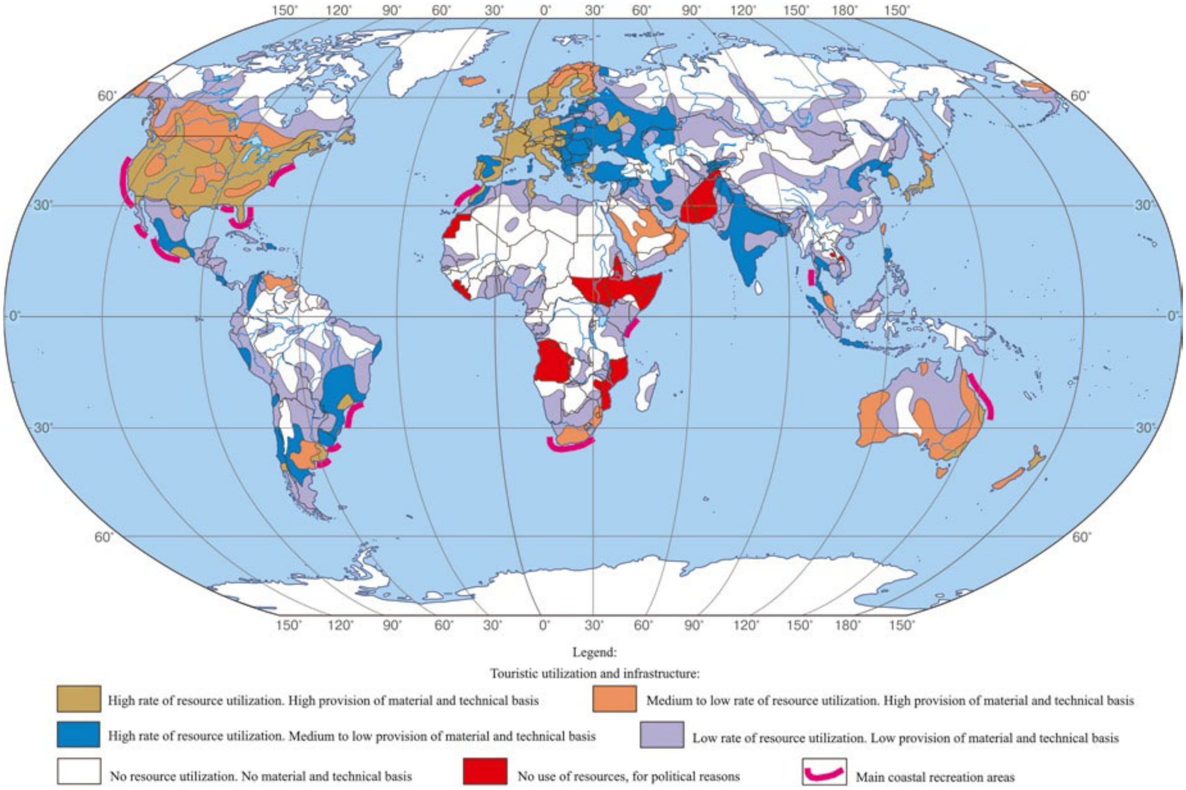

Fig. 13.4 Recreation and tourism (Resources and environment 1998. Reproduced with permission of Institute of Geography of the Russian Academy of Sciences)

Photo 13.20 A distinctive feature of places of public amusement is often the accumulation of large numbers of people in a small area. The photo shows holiday-makers in Dorset, United Kingdom (Photo credit: I. Kelman (http://www.ilankelman.org))

Photo 13.21 Accumulation of debris is often characteristic of places of unorganized mass leisure. The photo shows garbage on the southern shore of Lake Baykal near Listvyanka (Irkutsk oblast, Russia) (Photo credit: V. Kantor, Greenpeace Russia)

and Hergt 2003). Some species disappear when collected for *herbariums* and *bouquets*.

Recreational activity has especially strong impacts on *forests*. There are *five stages* of recreational effects on *forests*: (1) Forest litter is not disturbed, species composition is typical for the studied forest type, and the damage of undergrowth and shrubs is not more than 5%; (2) tracks have appeared, but they do not occupy more than 8% of the area; (3) routes cover 17% of the area, forest stand thinning is up to 10%, and meadow grass is appearing; (4) 40% of the forest has been trampled, only 50% of the tree stand has been saved, and turf cover has formed; and (5) 70% of the forest area has been trampled and some sick trees are still growing. At stages 4 and 5, the forest is no longer capable of self-restoration (Kuskov et al. 2005).

The influences of recreation on *wild animals* are different (e.g. anxiety factor, elimination of some animals due to hunting and fishing, habitat deterioration). The very presence of people can have very negative impacts on animals, especially at times of feeding, migration, breeding, and nesting. For example, in the Alps, partridges experience stress during hatching because of *hang-gliders* (Ingold et al. 1993).

When they encounter people, animals *run* away, spending 10 times more energy in comparison to the rest stage. As a result of this excessive tension, animals are often killed by predacious animals and birds (Balandin and Bondarev 1988). Scaring nestlings only two or three times is enough to cause them to *die* (Manush 1990).

Motor vehicles and sailing boats affect *aquatic birds* through noise and petrol spills (Bellan and Bellan-Santini 2001). Mooring on reefs and anchoring disturbs *seabed fauna* (Backhurst and Cole 2000). Tourism often promotes souvenir sales (corals, shells, turtle carapace, etc.). Though many animals suffer from direct impacts of recreational activity, indirect *habitat deterioration* is much more important.

Recreational activity leads to declines in *water* quality. Sewage pollution takes place next to coastal hotels. Many hotels use chemicals (chlorine or hydrate of sodium) to control sewage odours or to make oils and fats soluble.

Recreational activity may have serious *social impacts*. For instance, hotel construction can lead to the relocation of local residents. The introduction of many foreign citizens (tourists or contract workers) into an isolated local culture can seriously influence traditions due to the considerable differences in *lifestyle*. Some activities (e.g. excursions to archaeological sites) can be seen as *blasphemous* from the point of view of local residents (Buckley 2000).

Visual pollution of landscapes by tourism infrastructure also is created. It is especially noticeable for natural objects, which are appreciated for their *aesthetics* (waterfalls, gorges, etc.).

Many natural components, attractive from a recreational point of view, are very sensitive to anthropogenic interference. Uncontrolled tourism can damage those natural elements that are the *target* objects of the recreation. It is very important to preserve balance between scale and types of recreational activity, on one hand, and sensitivity and stability of the natural objects, on the other.

The impacts of recreational activity on natural components are illustrated by Photos 13.20 and 13.21.

Photo 13.22 During sports orienteering competitions, the use of sprint shoes sometimes provokes soils erosion. Trampling of grass and damage to shrubs are unavoidable. The photo shows the start of relay competitions in Finland (Photo credit: A.M. Mikhailov, 2005)

13.7 Sports Activity

At present, *sports* is an important part of global business. In 2003, the overall sales for the global sports market were estimated at US$75.6 billion, which is equivalent to the gross national product (GNP) of Chile, Pakistan, or the Philippines in the beginning of 2000. In the United States, the sports sector of the economy accounts for 1% of the GNP, and in the United Kingdom, it accounts for 1.5% (Palilov 2007).

Sports complexes and competition areas sometimes occupy *large areas* of land. For example, *golf courses* occupy 0.6% of the United Kingdom; on average, each course is 50–60 ha in size (Gange et al. 2003). In Switzerland, *pistes* cover 1% of the country (Rixen et al. 2004a, b). There are 12,000 ski lifts and aerial ropeways and 40,000 elevators from Grenoble, France, to Schladming, Austria (Heinrich and Hergt 2003).

The numbers of *people* engaged in different sports activities can be quite large. For example, there are 15 million *mountaineers* and *rock climbers* in the United States, and together with trekkers, their numbers reach 21 million people (Grijalva et al. 2002). The number of people *playing golf* in England is 2.15 million (Gange et al. 2003).

The influences of sports activities on the environment occur during the stages of *construction* and *exploitation* of sports facilities during training and competitions. In addition, not only the *participants* have impacts on the environment but also the *audience*.

At the *construction* stage, the environmental impacts of sports facilities are equivalent to those of many industries (e.g. vegetation destruction as a result of logging and machinery work, relief changes during excavation and shaping work, soil consolidation and erosion, local drainage increases, and noise pollution).

During *exploitation* of sports facilities, their impacts on the environment differ and depend on the sport. Many sports events affect *soils* and *vegetation*. For example, to increase the length of time ski slopes can be used, different chemicals are used (calcium and sodium chlorides, ammonia sulphate and nitrate), which leads to degradation of soils and vegetation (Geography of tourism 2009).

Consolidation of snow cover decreases its *heat-insulating properties* and leads to freezing of the

Photo 13.23 The maximum pressure on soils and vegetation during sports orienteering activities occurs in areas of 1.75-metre radius around control points. Around the worst affected control points, 50–75% of the vegetation within an area of 10 square metres suffered damage. The photo shows someone checking on a control point during sports orienteering competitions in Primorsky Krai, Russia (Photo credit: I.V. Strizkova, Far-Eastern Technical University, Vladivostok, Russia, 2004)

deeper layers of the soil (Rixen et al. 2003). Snow on skiing pistes melts 2–4 weeks later than normal (Keller et al. 2004). In turn, that delay leads to shorter periods of plant growth (Bradbury 2006). On the sites of skiing pistes, *productivity* and *biodiversity* are dropping (Wipf et al. 2005). On extreme spots where the snow cover is thin (tops, hills, steep slopes), ski edges damage nival vegetation and soil (Heinrich and Hergt 2003).

During *sports orienteering* competitions, the use of *sprint shoes* sometimes provokes *soil erosion*. During mass starts, trampling of *grass* and damage to *shrubs* are unavoidable. The maximum press is at the *checkpoint* areas (approximately 50–100 m) and especially in areas of 1.75-metre radius around them. Surveys immediately following competitions have shown, for the largest events, clear trails made by the orienteers for some 50–100 m into and out of the control points. Around the worst affected control points, 50–75% of the vegetation within an area of 10 m^2 (equivalent to 1.75-metre radius) suffered damage. Similar damage was reported for the start and finish areas (Review of research 2005).

Golf courses have certain influences on *soils* and *vegetation*. Usually, these effects are connected with the use of *fertilizers* and *pesticides* (Gange et al. 2003). *Shooting sport* leads to *lead poisoning of soils*. Research performed at five shooting ranges in Florida (United States) showed increased concentrations of lead (exceeding the acceptable level of 400 mg per kilogram) in the majority of soil samples (Cao et al. 2003).

Some sports have impacts on *surface waters*. For example, water discharges from *swimming pools* lead to chlorine poisoning of water bodies (Sa'ari et al. 2004). *Water-motor sport* competitions lead to petrol pollution (Heinrich and Hergt 2003).

Some sports activities have negative influences on the *animal world*. During mass *sports orienteering* competitions, for example, large birds and animals experience considerable stress. Some research conducted in Sweden showed that when a sportsman approached, *elk* (*Alces alces*) took flight at a 'flushing distance' of about 200–300 m and slowed down for another 1,300–1,500 m before stopping. The figures for *deer* (*Capreolus capreolus*) are 200–300 m and 600–700 m, respectively. The animals returned to their habitats over a period of 24 h, and some of them had signs of stress (Cederlund et al. 1981).

There is a similar problem with birds, which is especially serious during nesting and hatching. For example, during the Scottish Orienteering Championships in June 1987, concern was expressed about the disturbance at a critical period for certain ground-nesting birds, including *capercailzie* and migratory songbirds. Ornithological research done prior to the date helped to minimize the damage (Brackenridge 1988). The noise impacts on aquatic birds are considered to be strong during *water-motor sport* competitions (Environment 1999, vol 2).

Impacts on the *atmosphere* are connected with dust and exhaust during *motor vehicle* competitions, explosive gas emissions during *shooting* competitions, and emissions at other events. Refrigerators needed for

Photo 13.24 Impacts of shooting sports on the environment are connected with pollution of the atmosphere by explosive gas emissions and lead poisoning of soils. The photo shows a 10-metre air rifle shooting (Photo credit: V. Wittkowsky, 24 May 2005)

some sports (*hockey*, *skating*, *figure skating*, *curling*) make their contribution to ozone layer depletion.

Sports activity has its impacts on *resources depletion*, waste production, and other degradation of the environment. In sports like *mountaineering*, *rock climbing*, and *sports tourism*, the competitions often take place in areas untouched by human activities – sportsmen are the first polluters there. For example, in the 1950s, when the first attempts to climb Mt. Everest were undertaken, one or two expeditions were conducted annually. In the 1990s, their number had reached 50 expeditions a year. At present, degradation of the natural environment there (deforestation and waste pollution) is visible (Stevens 2003).

In general, sports activities have *insignificant impacts* on the environment. The influences on components of the natural environment can be seen in Photos 13.22–13.24.

13.8 Military Activity

The impacts of military activity on the environment occur during both *wars* and *times of peace* (e.g. play-wars; manoeuvres; routine military services; production or disposal of weapons, ammunition, and other equipment). Ranking of countries according their military expenditures is shown in Fig. 13.5.

During the last 5,500 years, humanity has suffered from 14,500 small- and large-scale *wars;* peace has lasted no longer than 292 years (Dovgusha and Tikhonov 1994a). The most frequent and *environmentally harmful wars* have taken place in arid zones of Africa and Asia (Relief and human 2007).

For example, the armies of Genghis Khan and Timur-i-leng destroyed many irrigation systems in Middle Asia, Mesopotamia, India, and the Caucasus, which led to desertification and salinization of the soils (Mazur and Ivanov 2004). Rome demolished Carthage and its irrigation systems (Kovda 1984). Other wars that were devastating to the environment include the Peloponnesian War (431–404 BC) between Sparta and Athens (Prokhorov 1998) and the Thirty Years' War (1618–1648) in Bohemia (Moral and ethical norms 1989).

In the twentieth century, World War II (1939–1945), the Vietnam War (1961–1975), and the Gulf War (1990–1991) had the *most serious effects* on the environment. During peaceful times, 0.5–1% of the globe's surface is still used for military purposes (Grinevich et al. 1995).

Weapon use, especially nuclear weapons, has the most devastating impacts on natural components. Global distribution of nuclear weapons is shown in Fig. 13.6. Other factors are things such as construction of fortifications, exploitation of wheeled and tracked transport, planes, and ships.

It is necessary to emphasize *two more aspects* of military activity (Govorushko 2009b): (1) environmental ways to conduct war and (2) ecocide.

During human history, some *elements of the environment* have been used for energy release and to inflict the maximal damage to the enemy. Elements

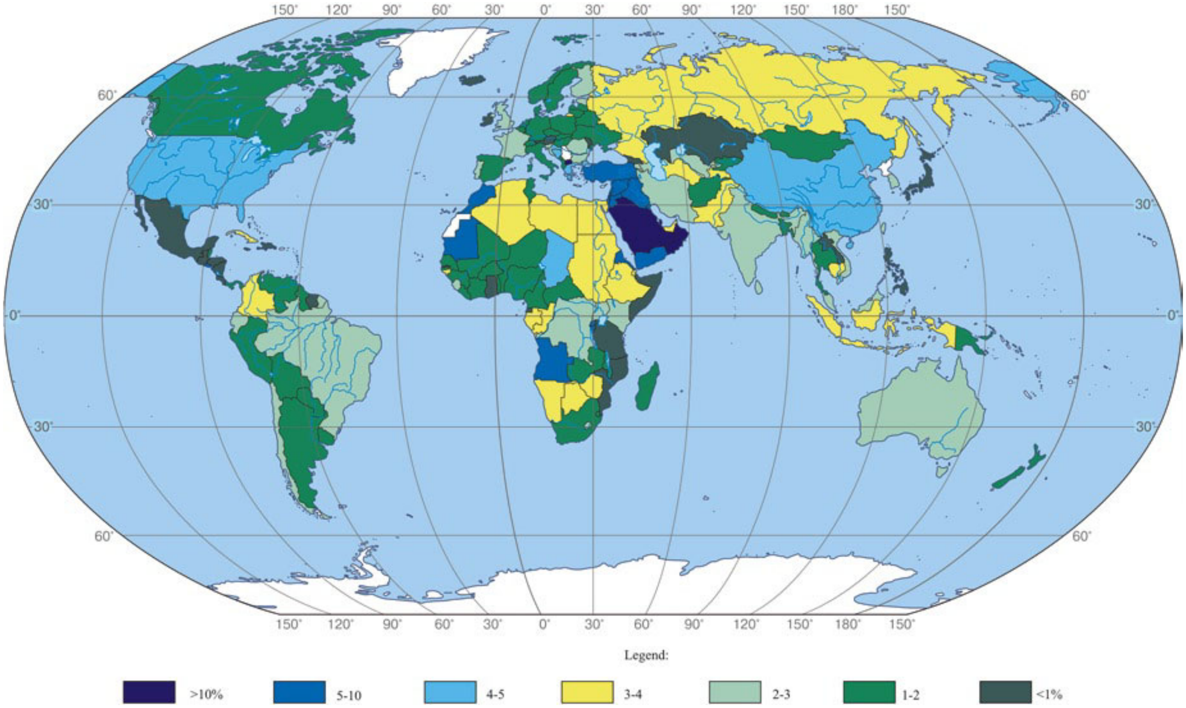

Fig. 13.5 Military expenditure as percent of GDP (http://en.wikipedia.org/wiki/Military)

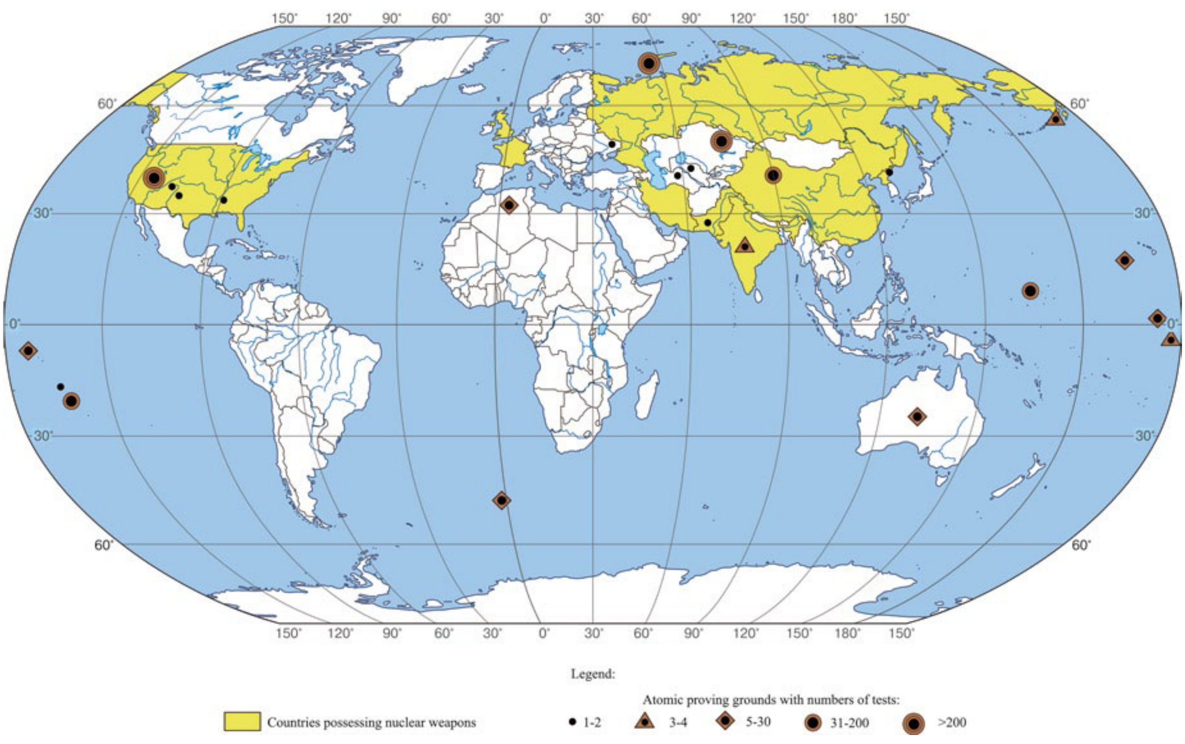

Fig. 13.6 Global distribution of nuclear weapons (Adapted from www nationalsecurity.ru; www.atomicarchi.com)

Photo 13.25 The impacts of military activities on the geological environment can be seen in disturbances of rock formation integrity due to explosions. The picture shows a crater after the 'Sedan' nuclear test (104 kt) on 6 July 1962. The explosion displaced 12 million tons of earth, creating a crater 1,280 ft (390 m) wide and 320 ft (98 m) deep in Area 10. Two radioactive dust clouds rose up from the explosion and travelled across the United States: one at 10,000 ft (3,000 m) and the other at 16,000 ft (4,900 m). Both dropped radioactive particles across the United States before moving to the sky above the Atlantic Ocean (Photo credit: National Nuclear Security Administration, Nevada Site Office)

such as the energy of forest fires, the water energy released when dams are broken, provocation of avalanches and rockfalls, and inland water contamination have been used.

The *first well-known example* is the war between the Persians and the Scythians in 512 BC. To prevent the attack of the Persian king Dariy, the Scythians used the tactic of 'burnt land', destroying all the vegetation and their houses while retreating (Mironenko 2002). During the *Franco-Dutch War* (1672–1678), the Dutch opened the sluices of the dams and flooded their territory to prevent the invasion of the French under the command of Louis XIV (Prokhorov 1998).

During the *Taiping movement* in China (1850–1864), the ruling Manchu dynasty used *fires* against the revolutionists. The flow of the lower Yangtze River was devastated (Westing 2000). Other examples, from more recent history, are the *bombing* of two big *dams* in the *Ruhr valley* by the English in 1943 (Accidents and catastrophes 1995) and the *demolition of dams* in the Netherlands by the Germans in 1944, when seawater flooded 200,000 ha (Prokhorov 1998).

Ecocide is usually defined as intentional destruction of the natural environment of the enemy. *A primary case* of ecocide occurred during the *Vietnam War*. Americans disseminated 57,000 ton of herbicides – *Agent Orange* – and around 23,000 ton of

Photo 13.26 The impacts of military activities on the geomorphologic environment are seen in considerable relief transformation. Trenches, pits, communication trenches, and blindages are dug during military operations. The photo shows a British trench near the Albert-Bapaume road at Ovillers-la-Boisselle, July 1916, during the Battle of the Somme (Photo credit: Ernest Brooks)

Photo 13.27 The fortifications of the First World War were 3,000 km long, and during the process of trench construction, more than 240 million cubic metres of ground was excavated. An aerial reconnaissance photograph of the opposing trenches and no-man's land between Loos and Hulluch in Artois, France, was taken at 7.15 p.m., 22 July 1917. German trenches are at the right and bottom; British trenches are at the top left. The vertical line to the left of centre indicates the course of a pre-war road or track (Photo credit: Imperial War Museum collection, United Kingdom, No. 1900–03.22)

defoliants (13 recipes), destroying 17 million hectares of vegetation (Sofronov et al. 2004). Fourteen million bombs were dropped (Dovgusha and Tikhonov 1994b). To extend the rainy season, planes disseminated iodine compounds of silver and lead (Mironenko 2002).

A *second* large-scale example of ecocide was the *Gulf War*, which had the following *results*, among others: six million barrels of oil were spilt into the water (Westing 2000), 550 oil well sites were burnt and emitted 125,000 ton of oil combustion products over a period of several months, and oil spills covered 2,500 km^2 of land. Huge numbers of birds died, and the populations of ichthyofauna dropped sharply (Oksengendler 1992).

Military activity influences almost all components of nature; it is estimated to account for 10–30% of all environmental degradation (Twentieth century 1992).

The impacts on the *geological environment* can be seen in disturbances of rock formation *integrity* (fragmentation, disintegration, mixing, dissemination) due to explosions, land use engineering, and other activities. Bombing and underground nuclear tests initiate *earthquakes*. There are many cases for which this connection has been proved (Balassanian 2005; Zhigalin and Nikolayev 2005; Nikolaeyv and Vereschagina 2006). For military services, the use of *underground space* is typical, which can be explained

Photo 13.28 The Gulf War was a large-scale example of ecocide. As a result of the war, 550 oil well sites in Kuwait were burned and emitted 125,000 ton of oil combustion products over a period of several months, and oil spills covered 2,500 km^2 of land. Huge numbers of birds died, and the populations of ichthyofauna dropped sharply. The photo shows burning oil wells in Kuwait in 1991 (Photo credit: University Corporation for Atmospheric Research)

by the need for maintaining secrecy, protection from bombing, and other purposes.

The impacts on the *geomorphologic environment* are seen in considerable relief transformation due to *explosions* of such weapons as bombs, grenades, and mines. Trenches, pits, communication trenches, and blindages are dug during military operations. The fortifications of the First World War were 3,000 km long, and during the process of trench construction, more than 240 million km^3 of ground was excavated (Mironenko and Sorokin 2007).

The impacts on *soil* are connected with its consolidation during troop movements, pollution after industries are destroyed, and other causes. *Vegetation* disappears due to fires, blasts, ammunition fragmentation, etc. In October–November 1942, for example, shrubs were destroyed in the *El Alamein* battle, which resulted in desertification (Westing 2000).

Military forces played an important role in *weed* dissemination between the seventeenth and twentieth centuries on islands in the Pacific and Indian Oceans. For instance, in 1768, the French introduced the *cactus Opuntia monocantha* in Fort Dauphin on south-eastern Madagascar, in an attempt to create an impenetrable barrier. On many islands in the Pacific Ocean, military forces brought *Bermuda grass* (*Cynodon dactylon*) (McNeely 2002).

Military activity leads to *animal* deaths or habitat deterioration. For example, when a marine mine of 100 kg explodes, all aquatic animals die within a 44-metre radius (Mironenko 2002). During the Second World War, many whales were killed because they were mistaken for submarines (Westing 2000). There have been many cases of military forces introducing exotic animals to different areas (see Subsection 5.11.7).

Atmospheric emissions released as a result of military activity comprise 6–10% of total air pollution (Twentieth century 1992); these emissions are connected with unavoidable fires, as well as with releases of dust, gases, and poisonous chemicals due to demolition of storage and industrial facilities.

The impacts of military activity on the environment are illustrated by Photos 13.25–13.28.

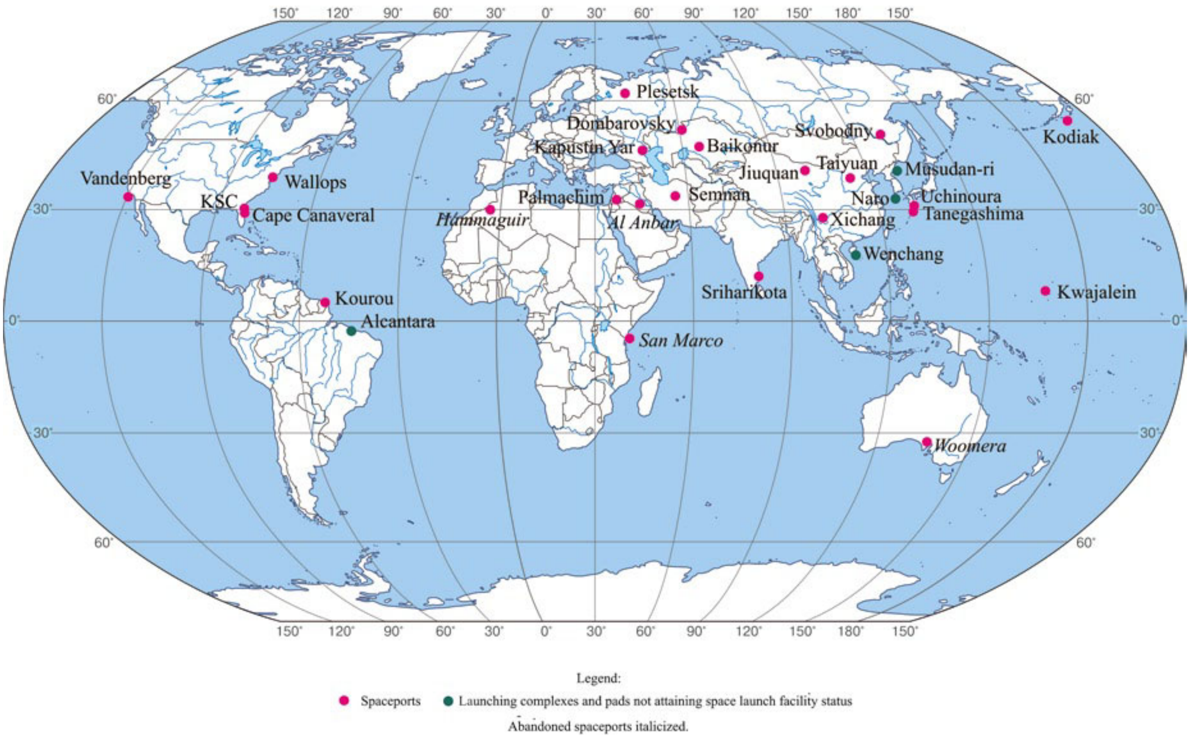

Fig. 13.7 Global distribution of spaceports (Compiled by author with the use of data from (spaceportal ru/index/08))

13.9 Space Exploration

At present, there are 28 spacecraft launching sites in the world (http://cosmoworld.ru/spaceencyclopedia/cosmodromes/index.shtml). The global distribution of spaceports is shown in Fig. 13.7. Every one of them is a complicated engineering construction. During launch and placement of spacecraft into orbit, the impacts on the environment are mainly due to the descent of carrier rocket parts.

First stages detach at altitudes of 60–90 km. When a stage hits the ground, the remaining fuel usually explodes and leaves a crater of 5-metre radius; fragments scatter for 100–200 m.

Second stages of carrier rockets separate at altitudes of 140–160 km. Due to heating in the atmosphere, the fuel explodes when the stage is 25–30 km above sea level. Fragments fall to the ground, covering a large area (Kondratyev et al. 2007).

When the *nose fairing* and *missile tail* (which do not contain fuel) fall, the impacts on the environment are small: Only the upper layer of the soil and vegetation are damaged, and the area is littered with fragments (Kretchetov et al. 2008).

Western spacefaring nations (e.g. the United States, France) build their launching sites on *shorelines,* and stages usually fall into seas and oceans. At the same time, *eastern spacefaring nations* (Russia and China) place launching sites *inland*, and detached parts fall primarily on their own territories.

The *area* where the fragments of the stages fall is large. For all active launching sites, it covers millions of square kilometres (Engineering ecology 2003). In Russia and other countries of the former USSR, their total area is 200,000 km^2, and the area polluted because of space activity is one million km^2 (Vronsky 2009).

The most *dangerous* matter in the carrier rocket is the components of its fuel – *unsymmetrical dimethylhydrazine* (*heptyl*) and *plutonium-238*. Global production of *heptyl* in 1981 was 35,000 ton (Roshchin and Frindland 2004).

Photo 13.29 The impacts of space activities on the atmosphere include pollution and ozone-layer depletion. When 1 ton of heptyl is burnt, 1.6 ton of nitrogen dioxide is emitted. Every launch of a 'Proton' missile requires 160 ton of fuel. Thus, at every launch, about 265 ton of nitrogen dioxide are emitted. The photo shows the launch of a Russian Proton rocket. This particular launch carried the Zvezda module to the International Space Station (Photo credit: National Aeronautics and Space Administration, 12 July 2000)

Space activity influences the following *components* and parameters of the environment: (1) atmosphere, (2) near-Earth space; (3) soils; (4) vegetation; (5) animal world; (6) surface waters; (7) geological environment; and (8) background radiation.

The impacts on the *atmosphere* include *pollution* and *ozone-layer depletion*. When 1 ton of heptyl is burnt, 1.6 ton of nitrogen dioxide is emitted. Every launch of a 'Proton' missile requires 160 ton of fuel. Thus, at every launch, about 265 ton of nitrogen dioxide is emitted. Around 30% of this amount is released at altitudes below 10 km, where nitrogen oxides promote ozone formation; when they are released at higher altitudes, they break ozone down (Piven 2006). *Chlorine* exhaust from the 'Shuttle' and 'Energia' spacecraft also leads to ozone depletion. One launch of a 'Shuttle' results in the loss of one million tons of ozone (Prokhorov 1998).

The main *factors* that affect *near-Earth space* are heat pollution, pollution with solid fragments, electromagnetic radiation from transmission systems, and radiation from nuclear power sources on satellites (Environmental problems and risks 2000).

With every passing year, the problem of *space waste* becomes more and more serious. Space waste includes things such as space vehicles that are no longer active, stages of carrier rockets and upper-stage rockets, and fragments of demolished missiles. Ten thousand objects in Earth orbit are tracked. There are hundreds of thousands of objects several centimetres in size and sometimes smaller (Korniyenko 2008). Earth orbit is the most polluted at altitudes of 850–1,200 km, where meteorological and remote sensing satellites are placed (Vronsky 2009).

Soils are impacted mainly by fuel. For instance, the first stages of the 'Proton' carrier rocket, which detach at altitudes of 35–45 km, still carry 500 kg of heptyl in their tanks. The fuel left in the propulsion packs and conduct pipes, as a rule, is spilled on the Earth's surface (Kasimov et al. 2006). Half of this pollutant is removed by run-off within the first 7 years, and after 50 years, only 5% of the heptyl remains (Popov and Yudakhin 2008).

Soil pollution affects *flora* and *fauna*. The smell of liquid fuel attracts birds and other animals. Tests on sheep that are grazed in areas where carrier rocket parts fall have shown the presence of heptyl in their tissues (Social-ecological consequences 2000).

Sea waters are usually affected to a far *greater* degree than *freshwater bodies*. Areas where detached rocket parts fall are located in the sea for the majority of spacefaring nations. Even Russia has 12 sea regions like this, with a total area of 9 million hectares. On average, 4,200 kg of heptyl, 6,820 kg of azotic acid, and 1,300 kg of azotic tetroxide fall in the Arctic Ocean every year (Vlasov and Krichevsky 1999).

The impacts on the *geological environment* are seen in increases in *earthquake* activity. In particular, it was noted after launches of heavy rockets carrying the *Apollo* and *Soyuz* spacecrafts (Nikolayev and

Photo 13.30 The second stages of carrier rockets separate at altitudes of 140–160 km. Due to heating in the atmosphere, the fuel explodes when the stage is 25–30 km above sea level. Fragments fall to the ground, covering a large area. The fuel tank of the second stage of a 'Proton' rocket that fell in the Altai Reserve (Russia) is shown (Photo credit: A.M. Panichev, Pacific Geographical Institute, Vladivostok, Russia, 1994)

Vereshchagina 2006). In addition, launches of rockets at Cape Canaveral (Florida, United States) have been connected with earthquakes in California (United States) and Mexico (Vlasov and Krichevsky 1999).

Radioactive pollution is especially dangerous in *emergency situations*. For example, in 1978, after the accident with the Soviet satellite *Kosmos-954*, 37.1 kg of spent nuclear fuel was disseminated in the atmosphere, and fragments of the reactor fell in northern Canada. On 21 April, the navigation satellite *Transit 5BN-3* (United States) did not enter the intended orbit, fell apart, and burnt in the atmosphere north of Madagascar; 950 g of plutonium-238 were dumped (Vlasov and Krichevsky 1999).

Falling parts are dangerous to *people*. For instance, in 1969, a fragment lost by a Soviet space vehicle fell on a Japanese trade ship and injured five sailors (Prokhorov 1998). On 5 July 1997, a second stage fell in the Altai region (Russia) and caused a short circuit in a power line and a transformer box to burn (Social-ecological consequences 2000).

The impacts of space activity on the environment are illustrated by Photos 13.29 and 13.30.

13.10 Health and Veterinary Services

Health and *veterinary services* are practical activities aimed at preventing and treating the diseases of humans and animals, respectively. These activities impact the environment mainly through *waste*.

Technically, *not all* the waste of health and veterinary facilities is *dangerous*. The greatest share of the waste (estimated at 60–85%) is classified as residential solid waste. The rest of the waste, however, is very dangerous for the environment because their contamination capacity is 1,000 times higher than that of household waste (Charnetsky et al. 2004; Rusakov et al. 2006).

Human and animal amputated limbs, blood and other body fluids (e.g. mucus, lymph), used bandages, disposable syringes, scalpels, gloves, expired drugs, X-ray film, and broken mercury thermometers are among the types of *dangerous* medical waste. They are produced as a result of both medical facility activity and medical and preventive measures undertaken by the people.

When it comes to the *volumes* of medical waste, they can be described as comparatively small. In

Photo 13.31 Health and veterinary services impact the environment mainly through waste. Human and animal amputated limbs, blood and other body fluids (e.g. mucus, lymph), used bandages, disposable syringes, scalpels, gloves, expired drugs, X-ray film, and broken mercury thermometers are among the types of dangerous medical waste. The photo shows medical waste in Sudan that was found along the main road (Photo credit: United Nations Environment Programme, from *UNEP Sudan Post-Conflict Environmental Assessment* report, 22 June 2007)

Germany, for example, it is a little more than one million tons a year, which is only 2% that of household waste (Daschner and Dettenkofer 1997). In Russia, the volume is three million tons a year (Charnetsky et al. 2005).

There are *two groups* that produce this waste: (1) health and veterinary facilities and (2) the general population. These groups differ in many ways (e.g. type of waste, waste treatment).

Health and *veterinary* facilities produce the full spectrum of medical waste; the associated dangers (e.g. toxicity, contamination, concentration) are much higher in comparison to the waste of the general population. This is true although these facilities follow safety procedures more strictly. However, there are exceptions. In 1996, for instance, 200 ton of clinical waste, including placentas and used syringes, were illegally disposed of in Hertfordshire, southeast England (Woodman 1996).

Medical waste of the general *population* comprises mainly *expired drugs* and *broken thermometers*. It is believed that *one third of drugs* is not used; when it expires, it is reprocessed and thrown away. Nevertheless, drugs are rarely reprocessed; most people just flush them into the sewage system or throw them away with household waste (Jones et al. 2001); in the same way, mercury thermometers are thrown into landfills.

Mercury thermometers represent serious environmental danger. The number of medical thermometers in Russia is about 100 million; each contains 2 g of mercury. In 1998–2000, nine million thermometers (containing 18 ton of mercury) were broken every year. Only 1 ton of mercury was disposed of at special facilities; the remaining 17 ton was thrown away into landfills and sewage systems. The number of thermometers at medical facilities in Russia was estimated at 7.5 million (Yanin 2004).

Still, the most serious problem is contamination of the environment with *drugs*. The acuteness of the problem is determined by the following *factors*: *First*, they often have low biodegradability (Christensen 1998; Stuer-Lauridsen et al. 2000). *Second*, for some of them, *synergism* is typical; that is, toxicity becomes greater when they combine with other substances (Kolpin et al. 2002).

In the early days of pharmacology, it was assumed that drugs are totally degraded in the human organism. Later, it was found that many of them are transformed insignificantly or *do not change* at all. Furthermore,

Photo 13.32 Oestrogen emissions from water purification facilities considerably increase numbers of hermaphroditic fish. The photo shows milt and hard-roe of hermaphroditic Siberian salmon in the Khabarovsk krai, Russia (Photo credit: I.I. Bubovich, Department of Fish Conservation, Okhotsk district, Russia)

Photo 13.33 The major contribution to the radiation dose obtained by the majority of men from artificial sources is provided by medical diagnostic means. The digital photofluorographic unit in one of the policlinics of Vladivostok is illustrated (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 9 June 2007)

they enter the sewage system with urine and can be still found after sewage water treatment. Some substances of pharmaceutical origin even can be found in drinking water (Haberer 2002).

Veterinary pharmaceutical drugs used in animal feed get into the environment as a result of manure storage overfilling or leakage, or when dung is put into soils (Kolpin et al. 2002).

Health and veterinary services mostly influence the following environmental *components*: (1) surface waters; (2) groundwater; (3) soils; and (4) the animal world.

In the early 1990s, drugs were first found in the *surface waters* of Germany. After that, a lot of research was done in Austria, Brazil, Canada, Croatia, England, Germany, Greece, Italy, Spain, Switzerland, the Netherlands, and the United States (Haberer et al. 1998; Stuer-Lauridsen et al. 2000; Zuccato et al. 2000; Jones et al. 2001; Kummerer 2001a; Kolpin et al. 2002; Bila and Dezotti 2003).

At present, more than 80 chemical compounds – drugs – are found in the environment (Haberer 2002). They were revealed in rivers such as the Rhine, Elbe, Neckar, Danube, and Po (Kummerer 2001a, b). Drugs were also found in the Baltic, North (Stuer-Lauridsen et al. 2000), and Adriatic Seas.

Drugs usually enter surface waters through *sewage systems*. Most of these drugs are analgesics, antibiotics, anti-epileptics, β-blockers, β_2-sympathomimetics, and lipid regulators (Jones et al. 2001).

Groundwater becomes polluted through processes such as filtration of contaminated waters at landfills containing household and industrial wastes, and manure drainage infiltration through soils. Numerous drugs (intended for treatment of symptoms such as obesity, pain, and fever) have been found in deep underground layers. The most common are such popular drugs as *diclofenac* and *ibuprofen* (Kummerer 2001b). Groundwater can also contain *iodinated contrast agents* (Haberer 2002).

Of all representatives of the *animal world,* drugs influence mostly *hydrobionts*. In many rivers in Great Britain, for example, the numbers of hermaphroditic fish have increased considerably. This development is believed to be connected with *oestrogen* (including EE2) emissions from water purification facilities (Christensen 1998). The presence of this drug in Lakes Erie and Ontario resulted in males of *perch* having not just male genitalia but also rudimental female organs. Their sexual behaviour changed, and they became infertile (Kolpin et al. 2002).

Other groups of drugs – for instance, *analgesics* and *sedatives* – are also of interest. *Barbiturates* have been reported to influence DDT metabolism in fish. They also may modulate behaviour and predator–prey relationships by *lowering swimming velocity* and influencing *reaction* times (Kummerer 2001a).

Thus, the influences of health and veterinary services on the environment are the cause for *deep concern*. Many problems still *need to be investigated*. It is obvious that the presence of some drugs in drinking water can lead to genetic mutations in people.

The impacts of health and veterinary services on the environment are illustrated by Photos 13.31–13.33.

13.11 Ritual Activity

A *rite* is a complex of ritualistic, traditional actions, without apparent practical value, but serving as a symbol of certain social relations and a form of their expression. In most cases, rites have a *religious background*.

The following are some of the *types* of rites that influence the environment: (1) sacrifice; (2) fire; (3) ritual construction; (4) making and destruction of puppets; and (5) pilgrimages to holy sites.

Sacrifice is a very widespread rite, typical for the majority of religions. In ancient times, it was practiced everywhere, and human sacrifice was common. History has preserved many descriptions of such rites. For example, ancient Germans had a tradition of sacrificing captives and their horses to the war god. Some tribes that lived in the first century AD on the territory of modern Denmark used to sacrifice people to the goddess Nerthus; Roman authors associated her with Earth Mother (Todd 2005).

At the dawn of recorded history, people practiced ritual killing during *burial rituals*. Those traditions were practiced for a long time in the nations of tropical latitudes. In some areas, ritual killings are still performed.

Rites of sacrifice, blood, and death were typical of the *Aztecs*. They were practiced less by the *Maya* (Yucatán Peninsula). Every year, 20,000 people were sacrificed on the flat roofs of pyramids. In 1486, when a new temple was hallowed in the Aztec capital city of Tenochtitlan, 70,000 people were murdered in just one day. During their invasion into Mexico, Hernán Cortés and his companions counted 136,000 skulls of sacrificed people in one of the biggest temples there (Golubchikov 2005).

After a time, the majority of nations began to sacrifice different *animals*. In the Harz Mountains (Germany), there existed a custom of burning *squirrels* on Easter; in the department of Ardennes (France), *cats* were burned on the first Sunday of fasting. In some regions of Greece, *oxen* were sacrificed; in south India, *goats*; and in the southern part of Celebes (Sulawesi) island, *swine*.

Sacrifice very often has a certain *objective*. For example, to *invoke rain* in Bohemia (Czechia), *frogs*

Photo 13.34 Immersion of idols is widespread in India. This custom introduces considerable pollution into water bodies. Though the idols themselves are made of inert materials, their paint contains considerable amounts of toxic metals such as lead, arsenic, chromium, and mercury. Devotees immerse an idol of Lord Ganesha at the Krishna River on the final day of the Ganesha festival in Karad in Maharashtra (India) on Thursday, 3 September 2009 (Photo credit: Bizsol Advisors Pvt. Ltd (India))

Photo 13.35 Rituals associated with the use of different trees have been widespread. The classic example is Christmas trees. The photo shows a fir-tree market in Vladivostok, Russia (Photo credit: S.M. Govorushko, Pacific Geographical Institute, Vladivostok, Russia, 26 December 2010)

were noosed; in the mountains of Japan, a *black dog* was sacrificed; in India, a *black goat*; and on Timor island, *black swine* (Fraser 1998).

Burial rituals very often involved the erection of special *structures*. Ancient Egyptian monumental tombs (*pyramids*), the Scythians' *tumuli* (round mound on top of a burial chamber), and *dolmens* (vertical slabs with another slab laid on top) are widely known. They can be found in the Mediterranean and Atlantic coastal areas of Europe, in the Crimea, and in the Caucasus (Matyushin 1996).

Many countries have the custom of burning *fires* during certain times of the year to dance around or jump over. Those traditions are rooted in ancient times. The numbers of fires can be great. For instance, during the Easter fire celebration in central and northern Germany,

Photo 13.36 During pilgrimages, serious damage to the environment is unavoidable, caused by the presence of considerable numbers of people concentrated in small areas. The photo shows Ganga at Har-ki-Pauri, Haridwar, during the River Dashara Festival, India (Photo credit: http://de.wikipedia.org/wiki/Ganga, 17 June 2005)

fires were burned simultaneously on the tops of hills, and sometimes, 40 could be seen at once (Fraser 1998).

Rituals associated with the use of different *trees* have been widespread. The classic example is *Christmas trees*; nevertheless, they are not only cut for the New Year. In many parts of Europe (England, Germany, France, and Switzerland), *pines* were installed in May. The Gypsy of Transylvania and Romania at the eve of St. George's Day (23 April) used young *willows*; in Boeotia (Greece), the biggest *oak* was taken (Fraser 1998).

There is a tradition of throwing *puppets* into water in many countries. For instance, in Bohemia, on the fourth Sunday of Lent, a doll called Death was thrown into the water (Fraser 1998); the Eastern Slavs, during the celebration of St. John the Baptist Day, drowned a puppet (Levkiyevskaya 2004).

In *India,* the rite of drowning idols is very common; there, it is called the '*immersion of idols*'. This is a multi-ethnic country with many religions. Annually, it has numerous religious festivals, which are accompanied by this ritual (Yeolekar and Bavdekar 2007).

In Bhopal (centre of the Madhya Pradesh state), September through October, for example, the rite of the idols *Lord Ganesha* and *goddess Durga* is conducted. Sixteen hundred idols were immersed in the suburban lakes of Bhopal alone (Avvannavar et al. 2009). This custom introduces a lot of *pollution into water bodies*. Though the idols themselves are made of inert materials, their paint contains considerable amounts of *toxic metals* such as lead, arsenic, chrome, and mercury (Bajpaiz et al. 2008).

Apart from that, during every rite, large amounts of oil and fat, flower garlands, and food waste get into the water (Vyas et al. 2008). Serious damage is caused to the workers' health. *Noise pollution* also is important. During such festivals, the noise levels reach 104 dB (Vyas et al. 2006).

Pilgrimages play an important role in many religions. Millions of people participate in pilgrimages annually. There are 12 *macro-regions* where *pilgrimages* take place: (1) Slavic republics of the former USSR (Russia, Ukraine, Belarus, Moldova); (2) Western Europe (Catholic dominance); (3) North America (Christian prevalence); (4) Latin America (predominance of Christianity and traditional beliefs of local populations); (5) north Africa (Islam dominance); (6) east Africa (dominance of Islam and enclaves of Christianity and traditional beliefs); (7) west Asia (dominance of Islam and enclaves of Christianity and Judaism); (8) south Asia (Hinduism. Buddhism, and enclaves of Christianity, Sikhism, and Jainism); (9) south-east Asia (dominance of Buddhism, Islam, presence of Christianity, and enclaves of Jainism); (10) east Asia (prevalence of Buddhism, Shintoism; areas of Christianity and Islam); (11) middle Asia (dominance of Islam); and (12) Tibet (prevalence of Buddhism) (Geography of tourism 2009).

During pilgrimages, serious damage to the environment is unavoidable, caused by the presence of *considerable numbers of people* concentrated in small areas.

Thus, rites make significant contributions to *environmental degradation*, and many *natural components* (e.g. vegetation, the animal world, soils, surface waters, the geomorphologic environment) are affected.

The impacts of rites on the environment are illustrated by Photos 13.34–13.36.

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Internet Resources

http://cosmoworld.ru/spaceencyclopedia/cosmodromes/index.shtml
http://en.wikipedia.org/wiki/Fishery
http://www.ehow.com/aquaculture
http://www.idausa.org/facts/hunting.html

Appendixes

Appendix 1 List of Maps

S.M. Govorushko, *Natural Processes and Human Impacts: Interactions between Humanity and the Environment*,
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Global Seismic Hazard Assessment Program: 1.1
Global Volcanism Program, Smithsonian Institution: 1.2
Goudie A.: 5.31
Govorushko S.M. (compiled by author): 1.3; 7.1; 13.7
Institute of Geography of the Russian Academy of Sciences: 1.4; 2.1; 2.3; 2.5; 3.6; 3.7; 3.8; 3.12; 4.6; 4.9; 6.1; 8.1; 11.2; 11.4; 11.5; 12.2; 13.4
International Council for the Control of Iodine Deficiency Disorders: 6.2
International Union for Conservation of Nature: 5.32; 5.34
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Appendix 5 Units Conversion

Adapted from http://www.easytrade.com/english/Help/Measure.htm

Weight conversion

The metric system		Anglo-American system avoirdupois		Anglo-American system troy weight		Chinese municipality
kg	g	pound	ounce	pound	ounce	tael
1	1,000	2.2046	35.2736	2.679	31.1507	20
0.001	1	0.0022	0.03527	0.00268	0.0321	0.02
0.4536	453.59	1	16	1.2135	14.5833	9.072
0.02835	28.35	0.0625	1	0.07595	0.9114	0.567
0.3732	373.24	0.82286	13.1657	1	12	7.465
0.0311	31.10	0.06857	1.0971	0.08333	1	0.622
0.05	50	0.1102	1.76368	0.13396	1.6075	1

Volume conversion

The metric system	Chinese municipality	British measurement	Columbian measurement
L	L	British gallon	Columbian gallon
1	1	0.22	0.264
4.546	4.546	1	1.201
3.785	3.785	0.833	1

Volume conversion (2)

The metric system		Anglo-American system avoirdupois			Chinese municipality
stere	cu. cm.	cubic yard	cubic foot	cubic inch	cubic foot
1	1,000,000	1.303	35.3147	61,024	27
0.000001	1	0.0000013	0.00004	0.06102	0.000027
0.7636	764,555	1	27	46,656	20.643
0.02832	28,317	0.037	1	1,728	0.7646
0.000016	16.317	0.00002	0.00058	1	0.00044
0.037	37,037	0.0484	1.308	2,260	1

Oil Supplies weight and volume conversion

	1 metric ton			
Country	Kilolitre	Columbian measurement	British measurement gal barrel	Columbian measurement gal
America and Indonesia	1.18	7.4	259.1	310.6
Iran and Saudi Arabia	1.19	7.49	261.8	314.5
Japan	1.11	6.99	244.5	293.3
Britain and Kuwait	1.16	7.31	255.8	306.7
Venezuela	1.09	6.84	239.2	287.4

5.1 Metric Units Conversion

Acreage conversion

The metric system		Anglo-American system			
centiare	square cm	square yard	square foot	square inch	square ruler
1	10,000	1.1960	10.7639	1,550	9
0.0001	1	0.00012	0.00108	0.155	0.0009
0.8361	8,361	1	9	1,296	7.525
0.0929	929	0.1111	1	144	0.836
0.00065	6.45	0.00077	0.00694	1	0.0058
0.111	1,111	0.133	1.196	172.2	1

Extent conversion

The metric system		Chinese municipalliy	Anglo-American system		
metre	cm	ruler	yard	feet	inch
1	100	3	1.094	3.2808	39.37
0.01	1	0.03	0.01094	0.03281	0.3937
0.3333	33.33	1	0.3646	1.094	13.123
0.9144	91.44	2.743	1	3	36
0.3048	30.48	0.9144	0.3334	1	12
0.0254	2.54	0.0762	0.0278	0.833	1

1 m = 100 cm = 1,000 mm

Weight conversion

The metric system	British measurement	Columbian measurement	Hong Kong measurement
metric ton	long ton	short ton	Sima load
1	0.9842	1.1023	16.535
1.016	1	1.12	16.8
0.9072	0.8929	1	15
0.05	0.04921	0.0551	0.8267
0.0508	0.05	0.056	0.8402
0.0605	0.0594	0.0667	1

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Geographical names are indicated in bold with capital letter, other names (nationalities, hurricanes, factories, etc.) are indicated in regular type with capital letter, Latin names of species are indicated in Italic, other names of plants and animals (common names of species, names of taxa, etc.) are indicated in bold Italic, terms (natural processes, diseases, etc.) are indicated in regular type with lowercase letter.

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